Volume 4 October 1958 No. 8

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Canadian Aeronautical Journal

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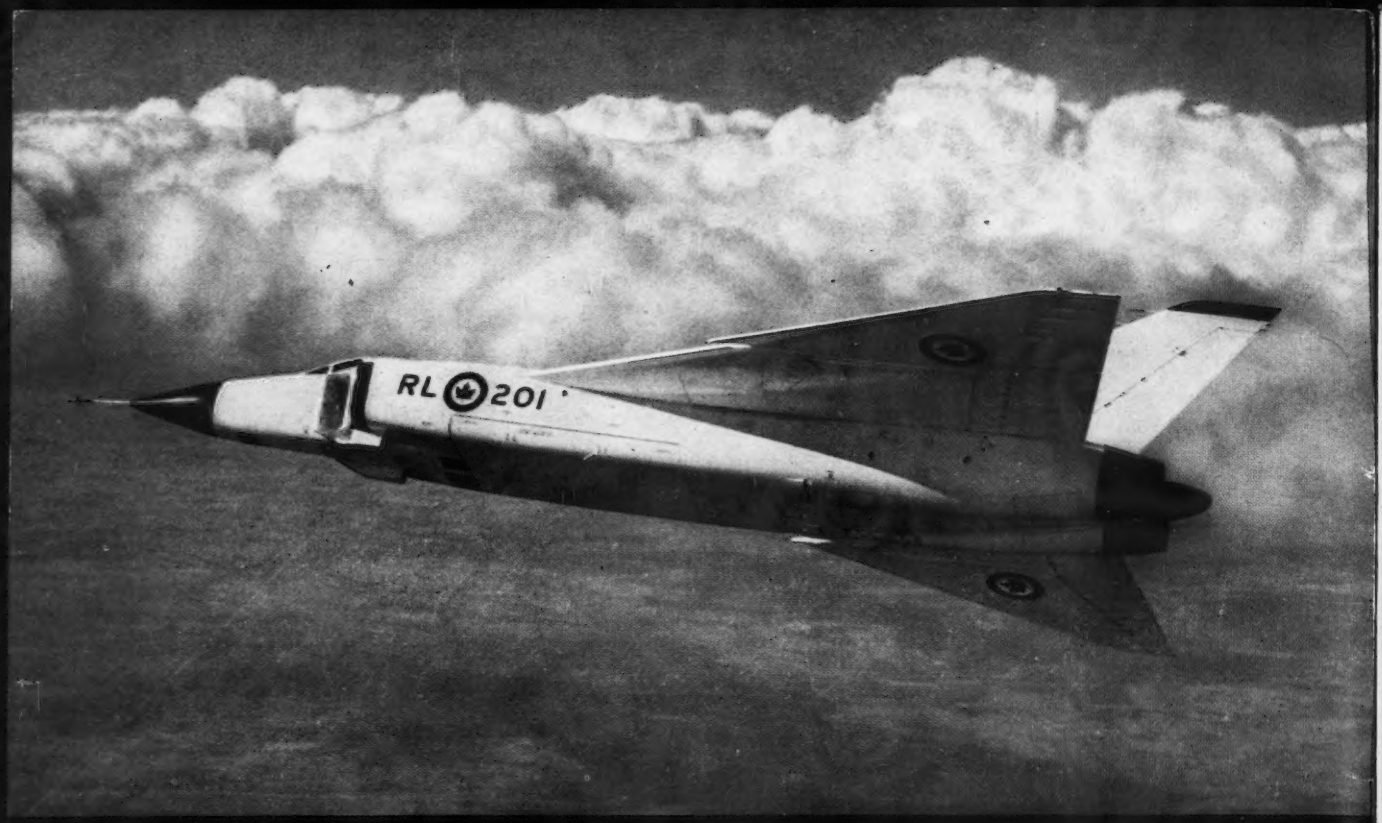
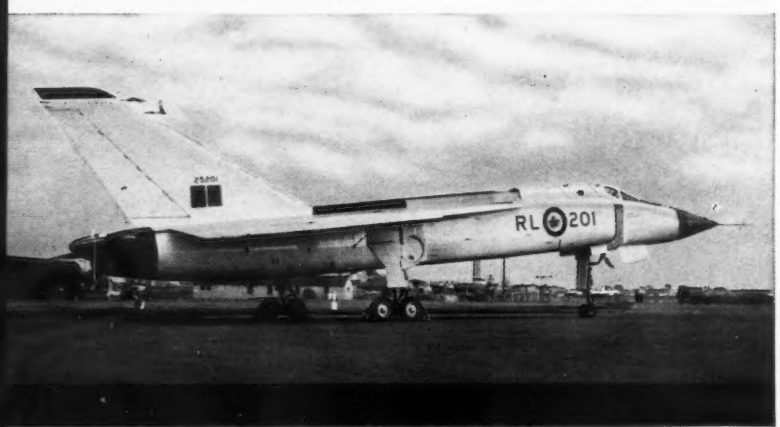
Published by the
CANADIAN AERONAUTICAL INSTITUTE
Commonwealth Building, 77 Metcalfe Street
OTTAWA



▲ The Avro Arrow is shown in flight during test manoeuvres over Ontario.

The Arrow weapon system is a bomber-destroyer having supersonic mission capabilities. ▼



The Avro Arrow is as big as a World War II bomber yet took off on its first flight in only 3,000 feet of the 11,000 foot runway at Malton. ▼

AN ARROW IN THE SKY

Since its first flight on March 25th, the Avro Arrow has been meeting the vigorous demands of its extensive flight test program. Proceeding according to plan, the Arrow flew faster than sound on its third flight, and more than 1,000 miles per hour on its seventh flight.

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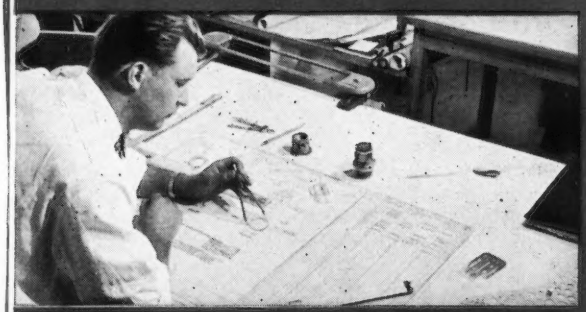

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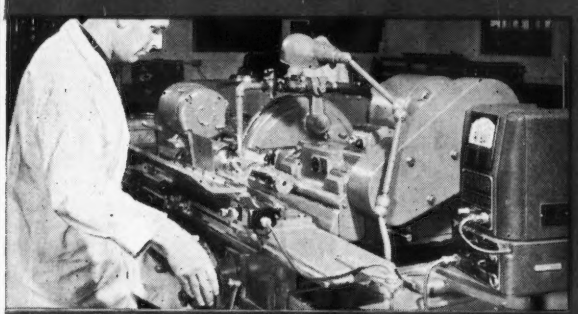

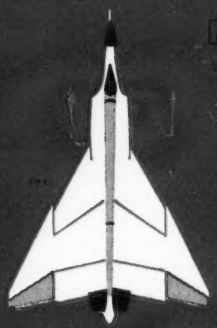

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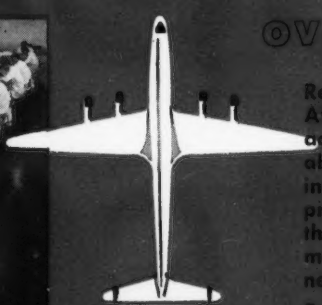

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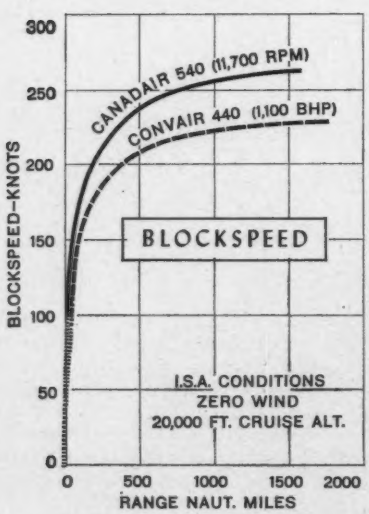
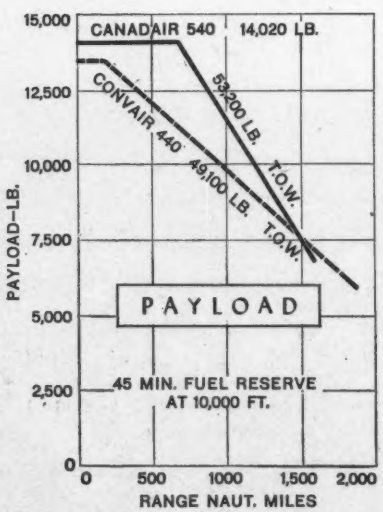


Graph at left shows the significant improvement in speed available in the turbine-powered "540" compared with the "440"—as much as 34 knots at a range of 1000 nautical miles.

Graph at right shows that the earning potential of the "540" is greatly increased. It is capable of carrying 48 passengers, plus their baggage, plus 4210 lbs. of cargo (total payload: 14,020 lbs.) a distance of 680 nautical miles. This represents a payload increase of 365 lbs. over the "440", and a range increase of 500 nautical miles.



Furthermore, with its Napier Eland turbine power, the "540"s max gross weight is increased 4100 lbs. over the "440" (up to 53,200 lbs.) . . . and the "540" can reach cruising altitude of 20,000 ft. in half the time (15½ mins. vs. 35 mins.). The "540" builds on the well-known and excellent record of the "440", and is altogether a new airliner unsurpassed in performance characteristics and earning power.

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Subscription—$4.00 a year. Single copy—50 cents.

Published monthly, except in July and August.

The Institute is not responsible for statements or opinions expressed in papers or discussions printed in its publications.

All communications should be addressed to The Secretary, Canadian Aeronautical Institute, 77 Metcalfe St., Ottawa 4, Ontario, Canada.

Authorized as second class mail, Post Office Department, Ottawa

Printed by The Runge Press Ltd., Ottawa, Ontario, Canada

CARIBOU

The De Havilland Caribou, powered by Pratt & Whitney R-2000 engines, made its first official flight on the 17th September, 1958.

EDITORIAL

A NOTABLE ANNIVERSARY — AND A FORECAST

THESE days we give little more thought to crossing oceans overnight than our grandfathers gave to a trip to the nearest village. It is not easy, however, to put one's self back into the frame of reference of Alexander Graham Bell's Aerial Experimenters who were, some fifty-odd years ago, laying the ground work for McCurdy's historic flight from Bras d'Or Lake in Nova Scotia. One may well conclude that the problems which faced that intrepid little group seemed much more difficult to them at that time than the question of reaching the moon appears to today's "Space Cadets".

During 1959 Canadians, and indeed the rest of the aeronautical world, will celebrate the 50th Anniversary of the first heavier-than-air flight in Canada. Actually — unless research has been faulty — J. A. D. McCurdy's takeoff on the 23rd February, 1909, was the first by a British subject in the British Empire. (As stated by J. H. Parkin in the May 1958 issue of the Canadian Aeronautical Journal, the Royal Aero Club of Great Britain credits Lt. Col. J. T. C. Moore-Brabazon with the first heavier-than-air flight by a British subject in the British Isles on the 2nd May, 1909.) This makes the event doubly important. Happily, John McCurdy is still alive and well and hopefully will be on hand to receive the honors justly due him.

Happily also, both the Royal Aeronautical Society of Great Britain and our own Institute of the Aeronautical Sciences will have the privilege of participation. It so happens that the Seventh Anglo-American Conference is scheduled in October 1959 on this side of the Atlantic. The two senior societies have watched with interest the development and growth of the CAI and have long since jointly agreed that the Canadian society should be drawn into partnership at an appropriate time. Many Canadians have attended all the conferences. During the recent International Congress in the Aeronautical Sciences in Madrid, members of the Councils of the three societies discussed plans for closer collaboration, and agreed that in the Fall of 1959 at least two of the twenty papers of the Seventh Anglo-American Conference should be by Canadians, and that the program of tours and plant visits projected in the northeast area of the United States should be extended to include two days in Canada. The probabilities are that the final conference dinner will be held in Toronto and that many of the delegates from the U.K. will take off for home from Canada.

The officers and members of the IAS are looking forward to this additional tie with our friends across the northern border. It will be a privilege to join with them in celebrating the Anniversary of fifty years of flight in Canada. Our joint meetings, such as the one just concluded in Ottawa, have laid a very firm foundation for closer collaboration on a broader international scale via the International Council of the Aeronautical Sciences and via an expanded Anglo-American Conference activity.

S. PAUL JOHNSTON
Director,
Institute of the Aeronautical Sciences

W. RUPERT TURNBULL LECTURER

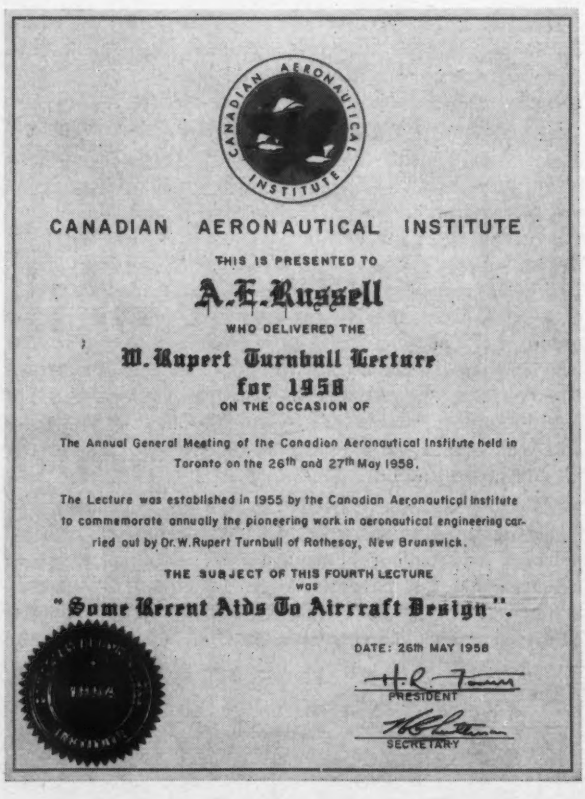
Dr. A. E. Russell

Dr. A. E. Russell, Director and Chief Engineer of The Bristol Aeroplane Company, England, delivered the fourth W. Rupert Turnbull Lecture on the 26th May, 1958, in Toronto. His lecture appears on the following pages.

Dr. Russell was born in 1904 and was educated at Fairfield Secondary School and Bristol University. He joined The Bristol Aeroplane Company in 1926; was appointed Chief Technician in 1931 and Technical Designer in 1938; and became Chief Engineer in 1944. In 1951 he was made a Director of the Company.

Dr. Russell has had a very distinguished career; he is a Fellow of both the R.Ae.S. and the I.A.S. and, in 1951, he was awarded the British Gold Medal. In 1949 he delivered the thirteenth Wright Brothers Lecture before the I.A.S. and, in 1954, the forty-second Wilbur Wright Memorial Lecture before the R.Ae.S.

He has published numerous papers in the R & M Series of the Aeronautical Research Committee and in the R.Ae.S. Journal.



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A.E. Russell

WHO DELIVERED THE

W. Rupert Turnbull Lecture for 1958

ON THE OCCASION OF

The Annual General Meeting of the Canadian Aeronautical Institute held in Toronto on the 26th and 27th May 1958.

The Lecture was established in 1955 by the Canadian Aeronautical Institute to commemorate annually the pioneering work in aeronautical engineering carried out by Dr. W. Rupert Turnbull of Rothesay, New Brunswick.

THE SUBJECT OF THIS FOURTH LECTURE WAS

"Some Recent Aids To Aircraft Design".

DATE: 26th MAY 1958

PRESIDENT

SECRETARY

SOME RECENT AIDS TO AIRCRAFT DESIGN†

by Dr. A. E. Russell*

The Bristol Aeroplane Company

MR. Parkin in the first of this series of Memorial Lectures gave an excellent account of the life and work of Wallace Rupert Turnbull. Here was a true pioneer, for Turnbull's interest in solving the problem of controlled flight preceded the achievement of the Wright brothers by some four years. By 1902 he had built the first wind tunnel in Canada. Thereafter his studies into the principles of stability and the means of achieving the most efficient combination of airframe, motor and propeller showed great insight and he did much to advance the early progress of aviation. The Canadian Aeronautical Institute has rightly recognized the merit of these early contributions and I am deeply aware of the honour of having the opportunity to give the fourth W. Rupert Turnbull Lecture. It is a great privilege to be here on this most important occasion and to serve a cause to remember one who helped to lay a sound foundation for our present most complex aeronautical edifice.

You will know that Turnbull came to England early in World War I. There he met Mr. Gordon England, who had formerly been with The Bristol Aeroplane Company but was then General Manager of Frederick Sage & Company. Sage's experience as shop fitters had, in the emergency, qualified them to be set up as aircraft constructors. In this newly formed design unit Turnbull served in charge of research and development. He took a special interest in aerodynamics including propeller design. After the war Sage's reverted to shop fitting and although another job was offered to him Turnbull preferred to return to Canada. Two of his colleagues, Mr. Clifford Tinson, the Chief Designer, and Mr. H. W. Dunn, joined the design staff of The Bristol Aeroplane Company, the former as Chief Draughtsman. It has been my pleasure to work with both for approximately thirty years, until their recent retirement. They were the sources of the following photographs.

The work of the early aircraft engineers was mainly directed towards gathering data on which to base a design. From the beginning, ordered research has been the prime means to excite imagination, to sustain intuition and to confound conceit. But at the start the wind tunnel was the sole entirely novel apparatus required; for the rest the normal experimental and theoretical resources of general engineering provided sufficient tools for the devotees of flight.

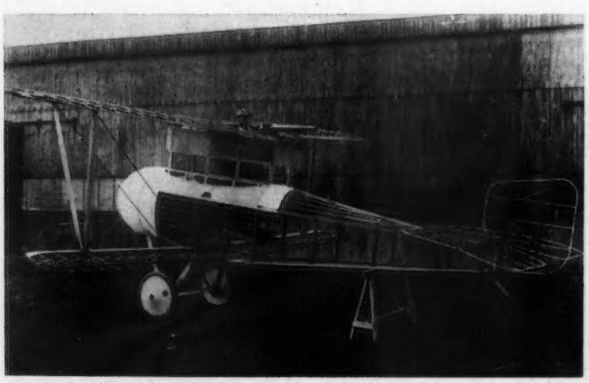
While the art remained primitive, ideas were dominant. The actual design process was indeed rapid, aided maybe by the luxury of a few slide rules. If the designer was not supremely confident, then a few hours would suffice to produce the proof by the loading of sand bags upon an inverted airframe. Perhaps the first refinement was to replace the sand by lead shot.

The supreme test was – would the new aircraft fly faster, further or higher? The basic questions that each succeeding generation has inherited.

This general state of affairs survived without fundamental change for 40 years. Aircraft materials changed from wood to steel to aluminium alloys; biplanes gave way to monoplanes; propellers changed pitch and landing gears became mechanized. But all this was achieved by refinement or, if you prefer, by complication, rather than by a radical change of methods.

A number of changed conditions has led to a new era. The four most important of these are the advent of the gas turbine engine, the development of guided weapons, the growth of civil transport and the cost and time of setting up new projects.

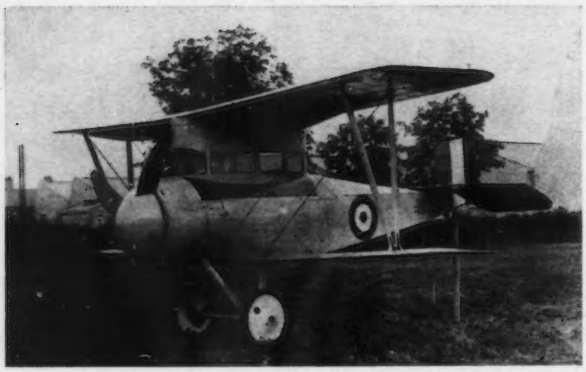
Hitherto the aero-engine designer faced substantial technical difficulties in packing more than about 4,000 hp into a single unit; also the achieved thrust fell as the forward speed increased, particularly as the propeller



Sage No. 2. Two seater scout bi-plane. Constructed July, 1916. View before covering showing the gunner's position.

†The W. Rupert Turnbull Lecture for 1958 presented at the Annual General Meeting of the C.A.I. in Toronto on the 26th May, 1958.

*Director and Chief Engineer.



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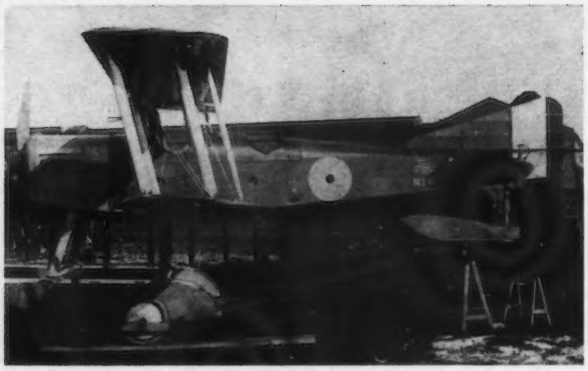
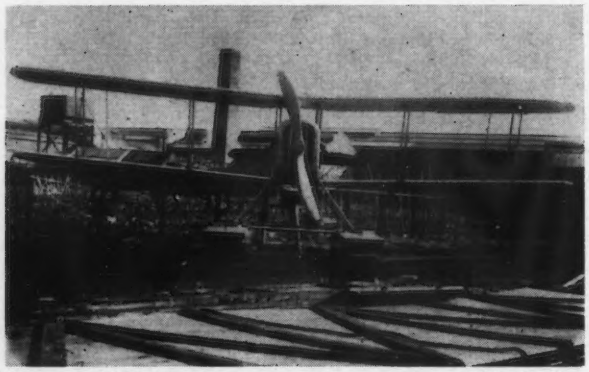


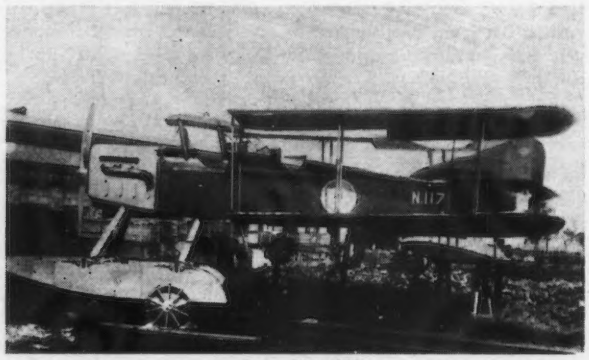
Sage No. 4B

Sage No. 3. Two seater bi-plane for primary training especially designed for slow landing on bad ground. Constructed November, 1916.



Sage No. 4C. Two seater training seaplane with folding wings. Constructed August, 1918.

Sage No. 3



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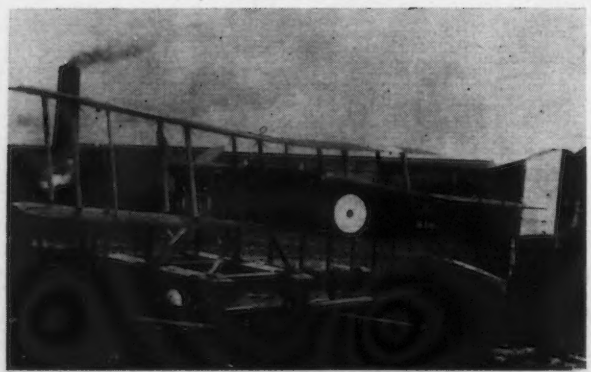
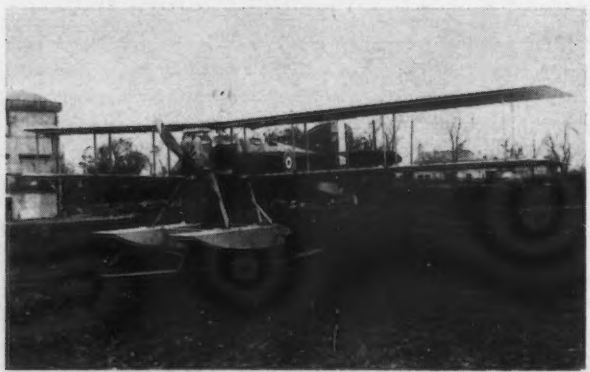


Sage No. 4B. Two seater seaplane designed for patrol duty with the Grand Fleet and subsequently adopted for training. Constructed June, 1917.



Short 260 hp Dover type seaplane constructed 1916

tip speed approached the speed of sound. Now with turbojet engines, the aircraft designer no longer faces an upper limit on thrust; as a result flight speeds are measured in terms of Mach number. In the regime of compressible flow the rules no longer follow straight lines of Newtonian-like simplicity but suffer distortions whose prediction is more akin to Einstein's complexity.

Guided weapons, which are rapidly taking over the major role in the aircraft industry, exemplify the revolution in techniques. Analysis of a complete weapon system comprising propulsion, guidance, control and warhead has exceeded the capacity of manual methods so that recourse to calculating machines has become essential. Also, a protracted period of development has required a comprehensive series of test vehicles designed to establish separate and collective data in a progressive pattern. Special instrumentation and telemetry has been devised to acquire this information. The creation of a mere flying machine is no longer a measure of merit; in operation a near miss of the objective serves no purpose. With such rigid constrictions on the margins of success no detail can be left to chance.

The third of the changed conditions is the spectacular growth of aircraft as a normal means of transport, patronized by a generally trusting public. Tremendous sums are now invested by the airlines in their equipment, while competition between the aircraft constructors is intense. Although hard economic operating considerations prevent civil transports from matching the highest performance of military aircraft, the stringent requirements for safety, reliability and economy demand unrelaxed application of intense engineering effort and extensive proving.

The last of the four conditions that I have chosen to illustrate is the time and cost of setting up new projects. Over the last twenty-five years it appears that the number of engineering man-hours employed up to first flight has remained approximately proportional to the product of the empty weight of an airplane and its design Mach number. Thus, by comparison with pre-war standards, it is typical for today's aircraft of similar purpose (i.e. fighter, bomber or transport) to require at least twenty times as much design effort. The same ratio of work applies to the phase between first flight and entry into service. This goes some way to define, if not to explain, the changed order of magnitudes.

Altogether it has become a most serious matter to prolong unnecessarily the gap between the decision to start a new project and deliveries to the customers. At the same time, liabilities arising from unsatisfactory behaviour in service prohibit economies obtained by deliberate omissions. There is no alternative but to explore fully all sources of possible misbehaviour in the airframe, the systems and the power unit. No effort can be spared in analysis, in experiment or test. Human judgment must be offered the best available aids.

These circumstances both stem from and breed vast programmes of research and development. In consequence technical libraries are overflowing with reports requiring an army of engineers to extract and apply the appropriate information. In this rapidly evolving science, calculations have increased to such an extent, in volume and complexity, that without the use of electronic and other aids to their solutions, they would take so long to finish that the answers might be of value only to an accident investigator.

COMPUTING AIDS

The two main types of electronic computers — digital and analogue — operate on different principles. Digital machines are essentially counting devices; analogue machines reproduce the problem under study in simulated physical form. In the early days of computers there was some controversy as to which of the two approaches was the better. There is in fact room for both; each has its own particular advantages and disadvantages when applied to specific problems.

Digital machines

The principal feature of digital machines is the general scope of their application. Any finite sequence of arithmetical operations can be carried out under the control of prepared instructions and hence any problem amenable to a numerical solution can be handled.

The arithmetical operations are performed by suitable circuits with numbers represented by voltage pulse-trains. Some form of storage (magnetic, electrostatic or acoustic) ensures that data is both fed into and extracted from the circuits, i.e. the so called "arithmetic unit", at high speed.

An impressive feature of these machines is the ease and rapidity with which they can be switched from one job to another. This results from a "programme", i.e. a detailed series of instructions previously prepared and fed in turn to the control unit, causing the machine to carry out the required sequence of operations. By arranging for these instructions to be in coded form, they can be recorded on the same medium as the numerical data and fed into the machine in the same way, e.g. punched cards, paper tape or magnetic tape. Programmes for specific problems are filed in a library and selected as required. The value of the computer is very much dependent upon the size of the programme library available.

An additional advantage arises in most large types of digital computers when the instructions are held in the storage of the machine as numbers (written in a numerical code). These numbers are available to be operated on by the arithmetic unit in the same manner as other numbers, so the machine is capable of modifying and adapting its own instructions. Hence, not only the number of instructions but the number of different types of instruction can be greatly reduced by a skilled programmer.

Limitations

The great capacity of digital machines offers a very wide scope of application in design calculation. They cannot be used however if a numerical method of solution to a particular problem is not known, nor if the responses of certain components of a system (e.g. a pilot) cannot be defined in mathematical terms. Also though the speed of operation is extremely fast, it is not always fast enough to simulate the true time scale of certain dynamic phenomena.

A further limitation is that the preparation and testing of new programmes is sometimes a long and labori-

ous task accounting for most of the time required to obtain the first solution. Certain problems (e.g. those requiring the solution of partial differential equations) may require excessive computing time.

Typical applications

Calculations that can be undertaken with much profit in time over other methods cover all stages of design. Some examples are as follows:

(a) Preliminary design – Investigations of the effect of changes in the major design parameters and the selection of optimum combinations.
(b) Preliminary structure design – Flight balances and overall aircraft accelerations. Distribution of bending moments, shear and torque.
(c) Structural detail design – Matrix methods are widely used for the formulation of strain energy analyses.
(d) Aerodynamic design – Distribution of lift and drag forces. Reduction of data from wind tunnels. Area rule calculations.
(e) Dynamic studies – Equations of motion in dynamic stability and response to dynamic loading.
(f) Aeroelastic design – High subsonic and supersonic flutter derivatives.
(g) External contours – Coefficients of analytical forms with ordinates as required.
(h) Performance analyses.
(i) Missile trajectory of miss distance studies.

Particular example

A more detailed description of a particular case will give a better appreciation of the value of digital machines. The case selected is the calculation of supersonic flutter coefficients by the Linearized Perturbation Theory. The computer employed was the English Electric "Deuce" shown in Figure 1.

The problem is to compute the oscillatory aerodynamic forces on a wing vibrating in supersonic flow. As is usual in flutter investigations, the assumption is made that the deflected form of the wing can be expressed in terms of a number of basic deflection 'modes'. Each mode will result in forces tending to produce deflections in the original and in the remaining modes. These are the forces to be evaluated.

Figure 1
English Electric "Deuce" computer

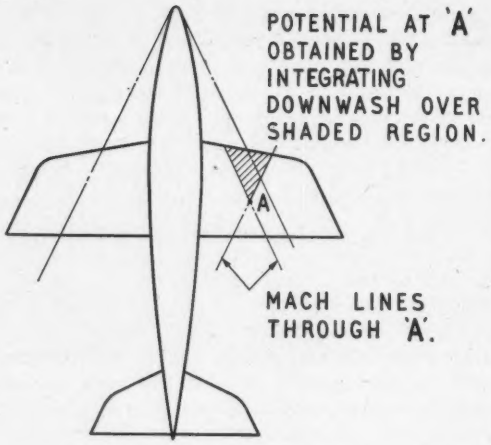


Figure 2
Calculation of potential diagram of representative point

The first step is to compute the downwash distribution resulting from oscillation in any given mode at the required frequency; this can be calculated from a knowledge of the deflected shape. The pressure distribution over the wing can be obtained from the potential distribution, so the potential must be computed at a large number of points over the wing surface. The calculation of this potential involves integration of the downwash function over a region of the wing bounded by the forward Mach lines through this point, the integration constants being calculated from the Mach number and frequency parameter (see Figure 2).

Having obtained the potential distribution and hence implicitly the pressure distribution in each mode, the deflecting forces acting in the appropriate modes can be derived by integration.

The programme for this work took one mathematician about six months to write and test; it consists of some 2,500 individual instructions punched on a pack of about 250 Hollerith cards. It took about 5 minutes to feed the programme into the machine together with the numerical data required for a particular solution. This data consists of the wing plan form geometry, the various deflection modes, the Mach number and the frequency parameter, requiring about 3 hours to punch.

A typical case involving flutter coefficients for 10 modes on a wing at M = 2.0 takes about 35 hours machine time, the whole process being completely automatic apart from the manual loading of data cards into the machine and the removal of result cards from the output punch.

This is an example of a calculation which is rendered feasible only by the use of a high speed computer. An estimate of the time required using desk calculating machines amounts to about 20 man-years.

Analogue machines

Despite the advantages resulting from the universal nature of the general purpose digital machine, it can usually be out-performed by a special purpose machine designed to suit a particular problem. It is worth building such a machine if the problem arises often enough;

Figure 3
Short Bros. computer used for simulation

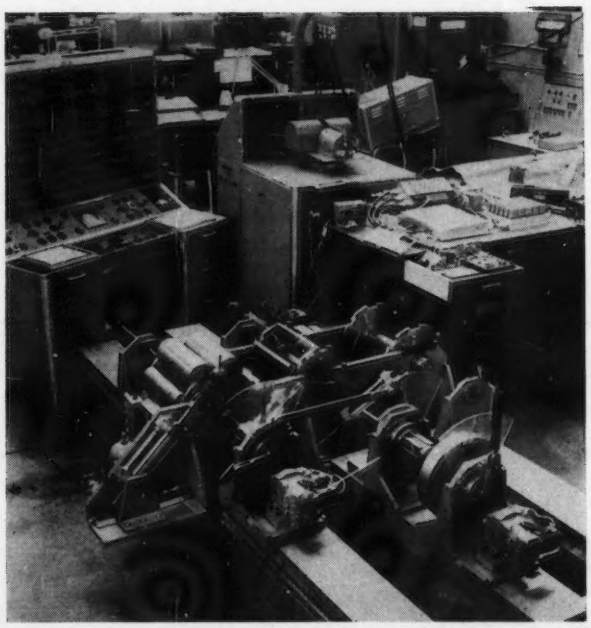


Figure 4
Short Bros. computer in a study of an autopilot and power control system

in this case the analogue approach offers many advantages in speed and in ease and economy of operation.

Differential analyzers

Many problems demand the solution of differential equations; these can be handled most conveniently by electronic differential analyzers. Such machines can be given great flexibility of application if they incorporate numbers of basic computing elements which can be interconnected through a control panel. Analogues of particular equations can then be rapidly selected.

A special advantage of these machines is that dynamic problems arising in stability and control, gust and landing loads, structural response and servo mechanisms can be investigated in the true time scale. Thus, it is possible to include actual items of equipment or a human operator in an otherwise simulated system.

Thus, for example, in a study of takeoff stability the Short Bros. computer, shown in Figure 3, was used to simulate the aerodynamic and kinetic behaviour of an aircraft and so feed information on aircraft attitude and speed to instruments in a cockpit simulator. Response to the pilot's control movements was presented on the instrument display.

In another example, illustrated in Figure 4, the computer was used in a study of the performance of an autopilot and power control system. Control system sensing elements were mounted on a rocking table, the angular movements of which simulated the aircraft motion. A spring loading device represented aerodynamic hinge moments of the control surfaces. Pen recorders controlled by the computer showed the response and stability of the system under disturbances.

A special machine has been built by Bristol Aircraft Ltd., (Figure 5), to solve the differential equations used in flutter calculations. In accordance with normal practice the aircraft motion is idealized and considered as made up of motion in a limited number of separate "modes" or degrees of freedom. Interaction or cross-coupling may be caused by any of the aerodynamic or structural forces and if none of these cross-coupling terms are neglected then for n degrees of freedom the motion will be represented by n simultaneous differential equations.

Figure 6 shows in simplified form the principle of the electrical circuits for one degree of freedom. The displacement x is represented by a voltage whose variation with time follows (to some time scale) the variation with time of the displacement in the physical problem. This voltage is obtained by using an amplifier circuit to integrate with respect to time and voltage representing $\dot{x}$, which in turn is obtained by integrating a voltage representing $\ddot{x}$. The potentiometer principle is used to multiply these three voltages by the appropriate coefficients A, B, C, D, E, V and V^2, forming the five terms of the flutter equation in the form of five voltages $A\ddot{x}$, BVx, CV^2x, $D\dot{x}$ and Ex. These voltages are fed to a summing amplifier which equates their sum to zero.

The Bristol flutter simulator has been designed to deal with up to six degrees of freedom. The variation

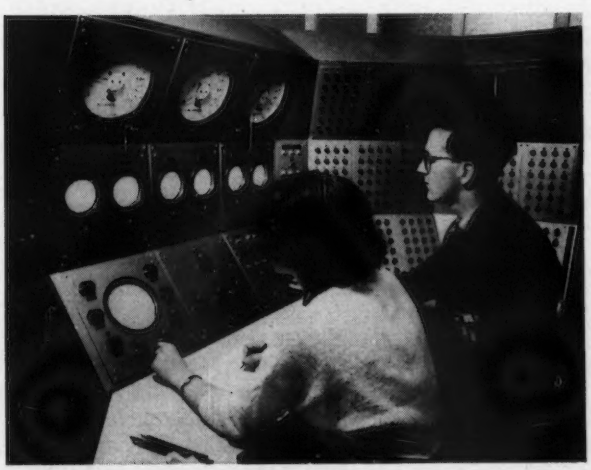


Figure 5
Bristol Aircraft computer used in flutter calculations

$$A\ddot{x} + (BV + D)\dot{x} + (CV^2 + E)x = 0$$

WHERE :-

A — SUM OF STRUCTURAL AND AERODYNAMIC INERTIA FORCES
B — AERODYNAMIC DAMPING FORCE
C — AERODYNAMIC STIFFNESS
D — STRUCTURAL DAMPING FORCE
E — STRUCTURAL STIFFNESS
X — SOME TYPICAL GENERALISED CO-ORDINATE DEFINING THE DISPLACEMENT ASSUMED TO VARY HARMONICALLY AT FREQUENCY ω.
V — VELOCITY

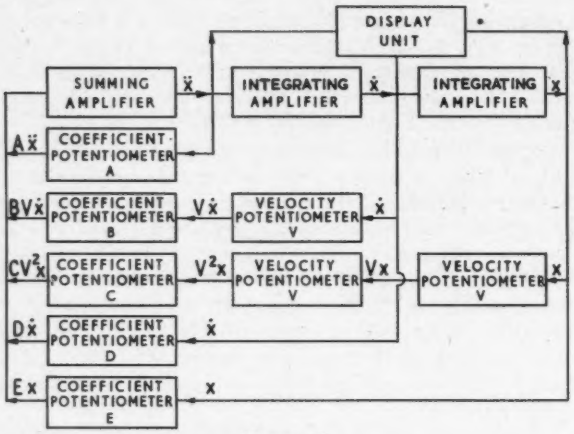


Figure 6
Bristol flutter simulator

with time of the quantities x, $\dot{x}$ and $\ddot{x}$ can be displayed in graphical form on cathode ray oscilloscopes: meters are provided to show the frequency of oscillation, and the amplitude ratio and phase angle between selected degrees of freedom. The velocity and frequency parameter, and the flutter coefficients A to E can be rapidly set up on the control panel, so it is a simple matter to explore a wide range of conditions by varying the appropriate parameters.

It is of interest to note that although this machine was designed for the strictly limited purpose of solving the flutter equations, it has been found possible, by means of a comparatively small extension to the circuits, to adapt it for use in helicopter ground resonance studies. Here we are concerned with investigating the conditions under which the out-of-balance forces at the rotor head can get into resonance with the structural stiffness, damping and inertia forces resulting from deflections and displacements of the fuselage and undercarriage.

Passive networks

In some cases direct mathematical analogies exist between idealized electrical circuits and other physical systems which may be mechanical, elastic or thermal. A network of electrical components including resistors, capacitors, inductances etc. can be assembled in a corresponding form such that the distribution of voltage and current in the network will be analogous to the distribution of the physical quantities in the original system.

One special problem is the investigation of kinetic heating of the surfaces of supersonic aircraft due to adiabatic compression in the boundary layer and viscous effects. Heat transfer to the structure is mainly by forced convection though radiation effects may be significant at high altitudes. Within the structure thermal conduction is unsteady until equilibrium is reached. The analysis is complicated by internal convection and radiation and by the presence of heat sinks, such as fuel tanks.

Knowledge of the internal temperatures is necessary to establish the environment in which the crew and equipment must operate and the effect upon the strength and stiffness of the structure, both local and general.

The derivation of the basic aerodynamic heating data for the appropriate flight conditions and aircraft geometry may be obtained by the use of a digital machine, but thereafter an analogue machine is more convenient. Such a computer can be versatile in scope and include the facility for two or three dimensional working.

Of two main types of network, resistance or resistance capacity, Bristol chose the latter. This has the advantage of being a more direct physical analogue and as such it is easy to visualize the significance of each element. Radiative and convective heat transfer can be readily represented. Computation of thermal stresses can be mechanized with instantaneous temperature and stress distribution, the solution of the problem proceeding continuously with time.

Resistance-Capacity network

The R.C. analogue is based on the similarity of the conductive heat flow within a homogeneous body and that of a charge in a non-inductive electric circuit. The heat flow path is represented by a network of electrical resistances arranged to represent the thermal resistance of the actual aircraft components. Condensers represent components having heat storage capacity. Direct current is used and potential differences across nodes in the network set up electrical currents equivalent to heat flow in the corresponding structure. Thermal stresses are obtained by coupled cathode followers to summing amplifiers used for integration of voltages in the analogue circuit.

Figure 7 shows how the network may be arranged to simulate an emptying integral fuel tank. It has been assumed that the fuel is in direct contact with the bottom skin and spar web. Condensers (Cf) are switched off in turn to represent the changing thermal capacity of the fuel. Resistances (Rs) represent heat transfer coefficients between the structure and the fuel.

Numerical solutions of heat flow problems in structures cannot be regarded as better than approximate. Consequently the critical conditions should be checked experimentally. For all except small specimens, the rapid heating necessary to induce the correct transient thermal conditions demands a very large heat supply. It seems impossible to check the effects of rapid cooling other than by actual flight tests.

Electrolytic tank

The electrolytic tank is another example of a direct mathematical analogy. The electrodynamic field around electrodes immersed in an electrolyte obeys Laplaces equation $\frac{\delta^2 v}{\delta x^2} + \frac{\delta^2 v}{\delta y^2} + \frac{\delta^2 v}{\delta z^2} = 0$, where v is the potential.

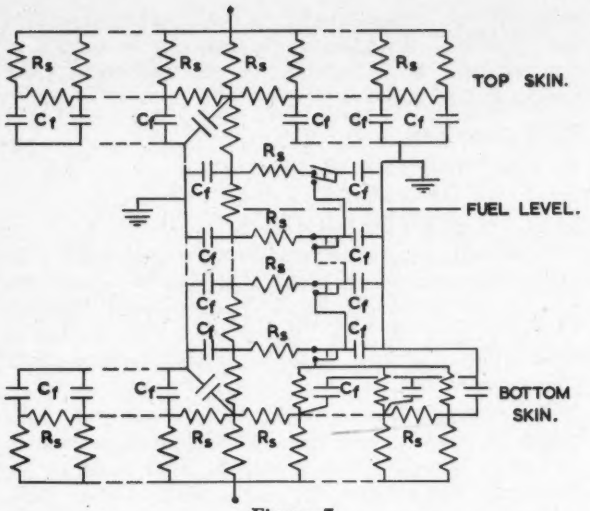


Figure 7
Analogue for integral fuel tank

This equation governs a great many field and potential flow problems, for example in elasticity, heat transfer and fluid flow, so that the electrolytic tank may be used to set up a potential field which can be plotted experimentally, and which will then also apply by analogy to a geometrically similar system in the elastic, thermal or fluid flow fields.

Isograph

There are of course a large variety of other special purpose analogue computers, of which it is worth mentioning the isograph, a device for finding the roots of high order polynomial equations. A machine of this type was designed and built at the Royal Aircraft Establishment and proved of much use in stability studies.

EXPERIMENTAL AIDS

An impression should not be gained that design offices now resemble a vast production machine shop, nor that the trend is towards a dominance of trust in calculations. It is true, however, that the large rise in the numbers of design engineers has been almost wholly in the technical offices and laboratories rather than the drawing office. While theoretical studies have obviously been greatly extended these are rarely if ever regarded as infallible. Therefore a complementary rise in the volume of supporting experimental evidence has become essential.

Although much experimental work is related to particular specimens, certain general testing techniques have become well established. A description of some examples will follow.

Wind tunnel flutter models

Before the war, simple precautions were sufficient to avoid flutter. After mass balancing the flying control surfaces and satisfying structural stiffness criteria, the locations of the nodal lines of the torsion modes were measured with the finished aircraft mounted on low frequency supports. Higher speeds, reduced wing thicknesses and new plan forms have aggravated the task of ensuring that the critical flutter speeds exceed maximum flight speeds by an adequate margin.

Aircraft arrangements of shape, stiffness and mass distribution are first checked on the basis of estimates of the flutter coefficients (performed on a digital machine) and an exploration on an analogue machine covering a possible variation of the significant parameters. So that the design may not rely entirely on theory, experimental tests are made. These are:

(a) Flexible model tests in a subsonic wind tunnel.
(b) Free flight rocket models (if supersonic).
(c) Full scale flight tests.

Flexible models

Two main types of model are employed, the "idealized" and the "representative". Idealized models consist of a small number of cantilevers each reproducing the calculated bending and torsional stiffnesses and elastic axis positions. Aerodynamic form is provided by lightweight boxes attached to the cantilevers in such a way that no stiffness is contributed; these boxes carry ballast to represent the aircraft mass distribution. This type of model has been used successfully by many firms on both sides of the Atlantic for subsonic wind tunnel testing and, to a much lesser extent, for transonic tests.

The main advantages of this type of model are its simplicity, the ease with which parameters can be changed (e.g. mass distribution) and the fact that damage following a flutter incident is usually confined to the boxes. The major disadvantage is that reliance is placed on calculated stiffnesses and elastic axis positions. In certain cases as, for example, the fin-tailplane junction on a T tail configuration or for low aspect ratio surfaces with discontinuities, such calculations may not be very reliable.

The "representative" model places less reliance on calculated stiffnesses and allied parameters. An attempt is made to reproduce, in simplified form, the actual structure of the aeroplane.

Skin and main stiffeners are used in arrangements similar to full scale with load paths correctly followed. This type of model is comparatively new but has already proved its value in many applications.

Its main disadvantages are that parameters are difficult to vary and that damage following a flutter incident will usually be extensive. Idealized models are usually tested at low airspeeds; thus compressibility effects are ignored. Representative models are usually tested at full scale speeds and this is one of the reasons why flutter incidents on such a model are usually very destructive.

The design and manufacture of idealized models has reached a fairly stable stage. Stiffnesses and masses are fixed on the basis of similarity laws. The spars are machined from any convenient metal and the boxes fabricated from balsa and plywood or, in some cases, fibreglass.

Representative models offer much scope for the ingenious model designer. Stiffnesses and masses are fixed on the same basis as the idealized model but the structural material is now disposed in a representative manner instead of being concentrated along assumed elastic axis positions. Milling is used to produce very thin tapered skins and expanded foams can be used as fillers to stabilize the skins. Cold setting adhesives are widely used

to fabricate some items. Great care is needed at junctions because space and weight are often at a premium and bad design may result in quite unrepresentative structural failures on test. This is a specialist field which is difficult for a firm to enter without some guidance.

Test techniques

At first wind tunnel flutter model testing was quite simple. The aim was to measure flutter speeds for various configurations and to identify the flutter modes by cine-photography. Tunnel turbulence was usually sufficient to initiate flutter. Very little information on the sub-critical performance was obtained and such data is often most important.

At the next stage a simple form of transient excitation was introduced and the decay of the resulting oscillations recorded. Tunnel turbulence sometimes masks a deliberate transient and several modes may respond simultaneously. Such effects are difficult to interpret and if the transition to flutter is violent, warning of impending flutter is inadequate.

More recent work has been based on a study of a steady state response of the system to a sinusoidal input, i.e. a resonance test. If this is done thoroughly, the behaviour of all significant modes can be studied throughout the speed range. This is important because some modes may exhibit low damping at airspeeds well below the critical. Differences between the model and the aeroplane may well be enough to change zones of small damping from positive to negative or vice versa.

Free flight flutter models

The same two forms of model are used for free flight as for wind tunnel testing. The representative type is more usual however in view of the need for greater strength and the 1:1 speed scale.

In some cases the structure and methods of fabrication closely resemble those of the aeroplane. In consequence such models have considerable value in checking certain structural effects as stress distributions and influence coefficients are represented to a fair degree of accuracy. The cost of these models is usually much higher than an equivalent wind tunnel model.

Test techniques

Major reliance is placed on a telemetry set to pass information from the model to the ground station. This restricts the data output very greatly. It is not generally possible to use any form of controlled excitation and this could mean that a band of flutter extending over a fairly small speed range could be missed. The majority of tests adopt simple boost with very high initial acceleration and subsequent glide. A boost-sustainer-glide test is better but this involves a more complicated vehicle. Boost should not go beyond about 80% of design speed, followed by the sustainer slowly accelerating the vehicle up to maximum speed. Instability then has an opportunity to develop.

This type of test is of course valueless if kinetic heating effects are expected to modify the aeroelastic characteristics.

An alternative to an expensive series of free flight tests with each model only giving one test point is desirable. Success has been achieved with test specimens mounted on a sledge boosted to the required speed and then retarded. More instrumentation can be carried in this way and the same model can be used many times (unless flutter occurs).

Flight flutter tests

The two main test techniques are:

(i) Transient test
(ii) Steady state test

The early form of the transient test used 'stick jerking' as the means of excitation. This can be a dangerous exercise due to the uncontrolled nature of the response. This procedure has been largely replaced by the use of small explosive charges, fired in sequence so as to excite the desired mode.

All transient testing suffers from two main difficulties. In practice more than one mode may be excited, leading to interpretation problems. Also buffeting or turbulence can smother the results. Both of these difficulties can be overcome by using a steady state test similar to that described for wind tunnel models. With properly designed equipment, answers can be obtained even when buffet and turbulence levels are very high (signal to noise ratios of less than unity can be handled satisfactorily).

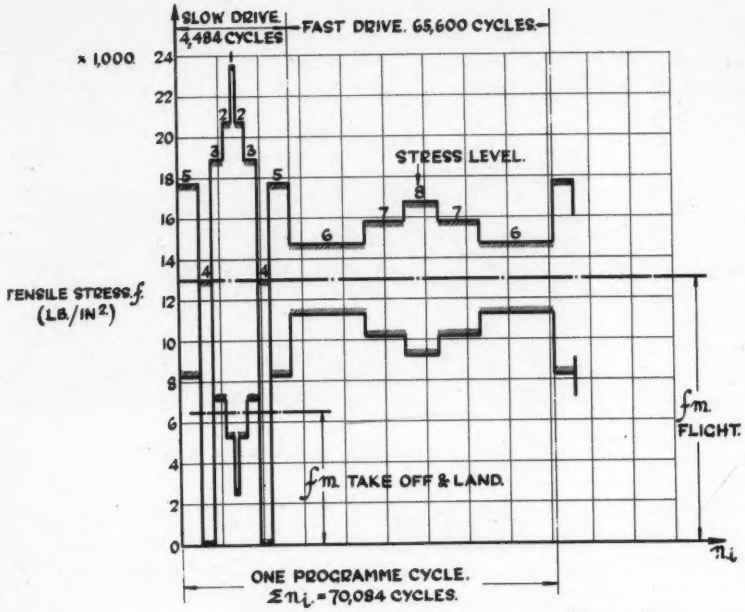
The equipment required for recording and analyzing such a test is fairly complicated and is best located on the ground. This leads to the need for a multi-channel telemetry link along which the flight data can be passed. Superficially this is a disadvantage but there are benefits, since it permits technicians on the ground to monitor the tests as they proceed and so speed up the programme or give early warning of an approach to flutter.

Comments

The aspect of design as described to this stage has been a cross section of the treatment of analytical problems, the solution and cure for which, once obtained, are unlikely to raise direct attention outside the ranks of professional engineers. Theoretical consequences of the treatment show little external evidence on an aircraft visible to a non-discerning eye. Admiration or even astonishment may be registered by the sight of a thin sleek wing without raising a thought concerning time dependent variables or aerodynamic and structural cross couplings. It is more likely that the designer will be given credit for his judgment of balance between the rival claims of the aerodynamic group for minimum drag and the structural design group for minimum weight. But, possibly, somewhere in the background a battery of machines, fed on a balanced diet of programmes containing all known ingredients of value, has been clicking away, accepting or rejecting precisely according to instructions, ever proceeding towards the terminus of its task. This method may lack glamour but it has the merit of extracting the maximum value from the data available without neglect or prejudice and with intuition confined to the details of the initial instructions.

MECHANICAL TESTING

Structural testing has also been greatly extended since the war. Not only have the long established forms of mechanical test, such as the normal static strength tests, been made more comprehensive in scope and more



STRESS LEVEL i	STRESS CASE	MEAN STRESS fm (lb/in²)	ALTERN. STRESS ± fa (lb./in²)	NO. OF STRESS CYCLES AT EACH LEVEL i ni
1	lg ± 22·5% U.D.S.	13,000	10,550	44
2	lg ± 16·5% U.D.S.	13,000	7,750	2×170
3	lg ± 12·5% U.D.S.	13,000	5,860	2×500
4	0·6g ± 0·5g	6,500	6,500	2×550
5	lg ± 10% U.D.S.	13,000	4,690	2×1000
6	lg ± 3·5% U.D.S.	13,000	1,640	2×25,000
7	lg ± 6% U.D.S.	13,000	2,820	2×5,500
8	lg ± 8% U.D.S.	13,000	3,760	4,600

ONE PROGRAMME CYCLE IS 1/20 OF THE ESTIMATED MEAN LIFE TO FAILURE FROM CONSTANT AMPLITUDE TESTS.

Figure 8

Britannia 100. Spectrum loading test on centre line on wing joint. The applied programme cycle

representative of actual flight conditions but greater information is now extracted. Faced with large and expensive specimens in complicated rigs, it is no longer sufficient to watch the increasing load with bated breath, awaiting the impending bang with but simple deflection gauges as indicators. Past experience suggests that at the first attempt the bang is likely to be premature.

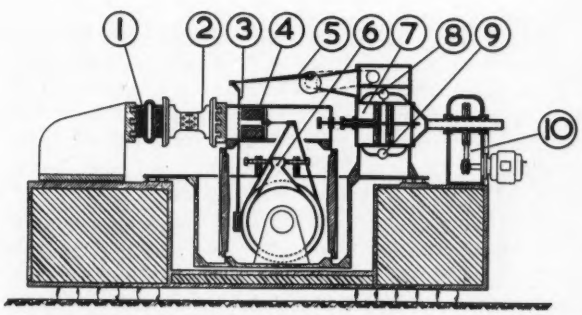
The development of electrical strain gauges, which can be attached in large numbers to a structure on test, now allows a fairly accurate picture of stress distribution to be drawn. This allows reinforcement or modification to sub-standard areas before the ultimate load is applied. Not less important is the sound basis provided for assessing local stress levels which, though below values defined by acceleration factors, may be high enough to be potential sources of fatigue failure.

Strain gauges

Electrical strain gauges have given the designer a third eye. They consist of short lengths of wire cemented to a surface such that they respond to the same strain as the adjacent structure. Strain induces a change to their electrical resistance which can be recorded and transcribed into stress.

Fatigue testing machines

The fatigue qualities of those areas of the structure where stress concentrations exist, by reason of cut out or local load input, should be subjected to detail testing before a major component test is undertaken. Until recently standard fatigue testing machines operated on a constant cycle of stress, a number of separate test specimens being required to establish the curve of variation of life with varying stress fluctuations. Unfortunately a wide scatter of results has been regarded as typical; also it is difficult to translate such test values so that they may represent the accumulating consequences of flight in a turbulent atmosphere.



(1) Dynamometer with control pick-ups
(2) Test specimen
(3) Exciter spring
(4) Interchangeable additional oscillating masses
(5) Connecting rod to resonance drive
(6) Mean load pre-setting
(7) Hydraulic slow drive
(8) Coupling pump
(9) Reversing rotary pump
(10) Carriage drive

Figure 9

Programme loading machine — Schenk P/B 30/200

Statistical data is available on the magnitude and distribution of gusts in the atmosphere; also fatigue testing machines are now available which can operate to a programme of varying stress cycles, adjustable as required.

A typical load spectrum as illustrated in Figure 8 can be applied to the machine shown in Figure 9 which has an automatic eight stage programme control.

Loads within a maximum of 16 ± 10 tons can be applied at speeds up to 3,000 cpm. This is a resonance drive, the two masses being the heavy machine bed itself and the oscillating head. A large leaf spring is excited by a motor driven eccentric and connecting rod. The sys-

tem works on the ascending branch of the resonance curve, so the load is strongly frequency dependent. This requires accurate speed control but it also permits a smooth change from one level to the next. Relatively infrequent high loads in the spectrum cannot be applied accurately at a rate faster than about 30 cpm, so an automatic change from fast drive is provided. The slow drive operates by hydraulic pressure, applied alternately on the outer faces of two pistons, thus generating the reversing loads. The space between the pistons is pressurized so that a clutch mechanism couples the hydraulic pistons to the oscillating head. A double helical spring applies the mean load by combined bending and torsion which is also maintained constant by automatic control.

Accessories to the machine include a load magnification device giving a maximum dynamic load of 200 tons, three and four point bending and an attachment for applying torsion.

Fatigue tests on detail fittings appear to be well nigh infallible in focusing attention on poor design features, as defined by high stress concentration at rapid changes of section. Each important fitting in a structure should be subjected to such examination.

The machine with its slow drive has also been used to study the rate of crack propagation in skin panels having different forms of stiffeners.

Tank fatigue testing

At the time when pressurized fuselages were adopted in design it was realized that there would be grave difficulty in calculating stresses where strains would be other than mainly circumferential. Accordingly, sections of the fuselage incorporating representative problems were built and tested under air pressure to ultimate design loads. This method was soon discarded as failure was explosive leaving doubtful clues as to the primary source of weakness. Also inevitable slow rates of pumping prevented frequent applications of load.

Immersion in a water tank was then adopted with the obvious advantage of minimizing the energy stored in the pressure fluid with consequential reduction of secondary damage after failure. Also rapid repetitions of load became possible.

Events, however, led to a more ambitious test procedure.

The Bristol water tank

A test cycle in the Bristol tank represents a complete flight including:

(a) takeoff with flaps deflected 15°,
(b) transition to steady flight with
(c) 18 applications of 10 ft/sec gusts,
(d) fuselage pressurization coincident with (c),
(e) transition from gust loading to approach with flaps at 45°, and
(f) final support on landing gear.

The cycle is automatically programmed and takes 3 minutes to complete. Torsional cycling of the rear fuselage underside gust loading of the fin with fuselage pressurization is dealt with by a separate test sequence.

Figure 10 shows a picture of an aircraft in the test installation.

Operation commences with the hydraulic jacks unpressurized and the aircraft supported at the landing gear

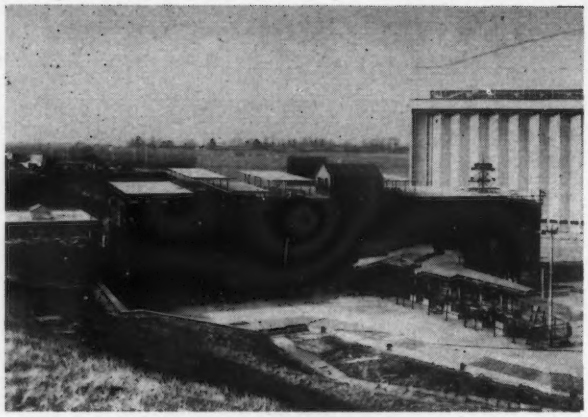


Figure 10
Aircraft in Bristol water tank

attachments. Pressure is first applied to the lifting jacks including those representing flap loads. On reaching the required values, a pressure switch is actuated and the programming unit is triggered forward to select the removal of flap loading and the application of steady flight and gust loads. At this point a further pressure switch causes the up-gust pressures to be removed and the pulsator unit is brought into action to apply the appropriate number of further cycles, ranging from loads representing 10 ft/sec up-gust to 10 ft/sec down-gust. Meanwhile, the pressure in the fuselage has been applied and maintained constant with compensation for specimen leakage.

At each transition, delay switches ensure that the correct loading is reached and held for a definite period. Accumulators are provided to eliminate fluctuations in the steady load jacks while the wings are flexing under gust loads.

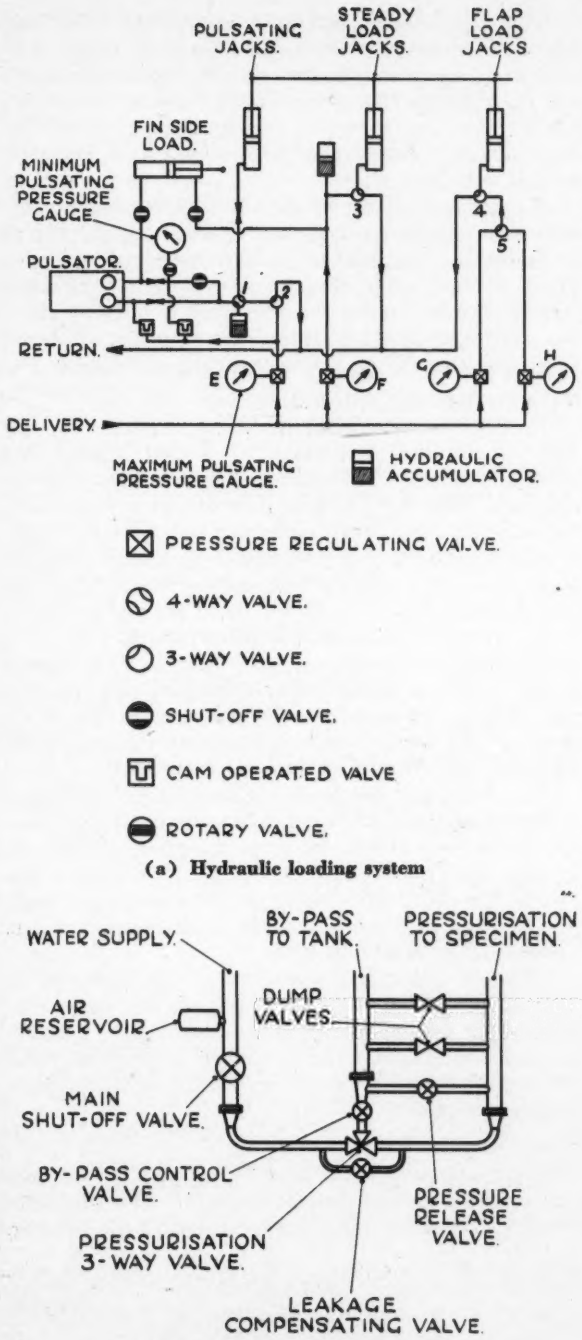
Figure 11 shows a simplified diagram of the structural loading by hydraulic jacks. For clarity, groups of jacks are represented by single items; in fact the steady load group consists of 14 jacks, the pulsating group 10, the flap loading group 12 and the tail loading group 3 jacks.

Figure 12 shows the hydraulic control console with the programme control unit adjacent.

Nine automatically operated safety devices are incorporated in the system to deal with possible emergencies. These might arise from single or combined failure of components, services, water seals etc. As an example, failure of a wing seal at the tank side might cause a rapid drop of water level. In this event the fuselage freight doors open to ensure immediate release of internal water.

It is possible to complete 180 cycles of loadings, representing an equivalent number of flights, in 24 hours. This time includes 2½ hours for transferring 300,000 gallons of water between the primary and secondary tanks to allow a routine visual inspection check of the structure.

It has become the practice not only to complete a prolonged life study of complete airframes under representative loading conditions but also to examine their



(a) Hydraulic loading system

(b) Pressurization system

Figure 11
Fatigue test loading and pressurization systems

'fail-safe' properties. At a later stage in the tank test deliberate damage is inflicted on important members, then a number of loading cycles are applied without intermediate inspection. This represents service operating conditions between approved Check IV periods. Rates of propagation of cracks and other forms of failure can be observed, thus giving guidance on action necessary to avoid potential hazards.

As yet, it has not been necessary to include thermal effects of aerodynamic heating into major fatigue tests. Imagination flinches at the very thought of having to devise appropriate equipment to test a high supersonic pressurized transport. Exploration of the effects combined with normal load factors for the smallest inhabited aircraft is sufficiently complex and expensive to tax most private resources. However, the task is eased considerably if the facilities are confined to cope with typical guided weapon sized components.

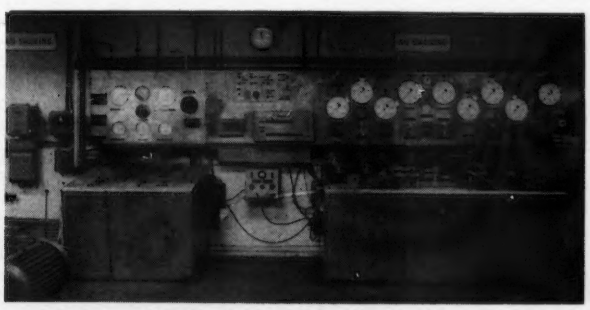
Kinetic heating simulation

Heating of structural elements under test at Bristol was first provided by quartz blankets rated up to about 13 Kw/sq ft. Later the now widely adopted tubular quartz infra-red lamps, capable of giving up to 60 Kw/sq ft, have been employed. Arrangements for a comparatively small test are shown in Figure 13.

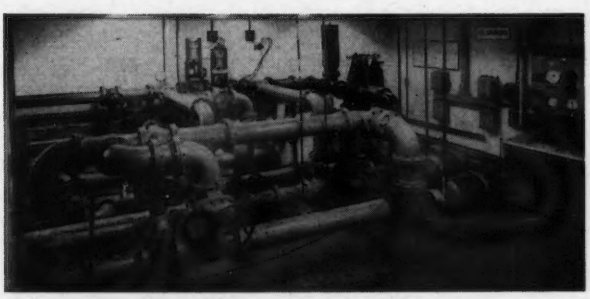
The power plant utilizes grid-controlled mercury-arc rectification of the three phase mains in 50 Kw units. Independent channels are required for control of heat distribution over a complex structure or the heating units can be gauged when uniform intensity is required over a wide area.

Control is normally effected by a closed loop temperature-time programme. The voltage analogue of the demand temperature is determined by the profile of a rotating cam and passes with a feed back voltage analogue of the actual skin temperature through an error amplifier to the magnetic amplifiers which control the grid circuits of the rectifiers. This method is a simplification of the complete analogy pending the development of digital function generators.

Closed loop control also enables a consecutive series of loads, applied by hydraulic actuators, to be imposed during heating. An automatic process stores the voltages produced by deflection and temperature transducers on



(a) Hydraulic control console



(b) Programme control unit

Figure 12

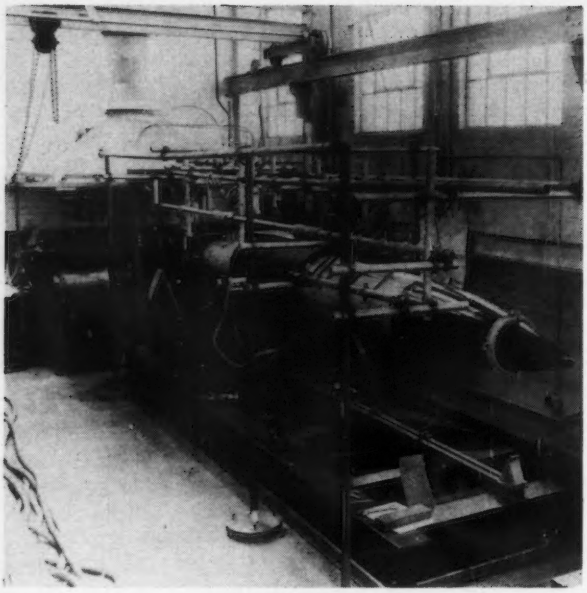


Figure 13
Kinetic heating simulation

magnetic tape. A full analytical and experimental treatment of transient and settled thermal stresses presents serious difficulties and it will take time before wholly satisfactory methods and equipment are available to the designer. While it is permissible to take some risks in the interest of military capacity, if commercial developments ever evolve into this environment unqualified confidence in safety will demand elaborate extensions to present equipment.

Acoustic tests

The devices described so far are part of an accessory kit of tools recently added to the designer's resources. In each case the need arose by reason of a special requirement within the general pattern of aeronautical progress. Their function meets the demand to justify analytical claims; they also serve as accumulators of experience and confidence. By contrast the following special acoustic equipment was designed initially to explore an old problem by modern methods.

Noise in excess has always been at least a human nuisance; the proximity of jet blast may also excite vibrations such as to produce failures in adjacent structures. Investigations into methods to exclude or absorb noise emanating from a normal source are complicated by the need to operate the source, i.e. the engine. The present method produces noise from acoustic exciters capable of noise levels up to 110 db. Large loudspeakers supply the source of excitation which is generally a pure tone or a simple combination of a few pure tones. The appropriate noise is obtained from flight tests. Pressure transducers are mounted on the aircraft skin and accelerometers on the fuselage frames; the outputs are analyzed into frequency components and the level of each harmonic recorded as a constant frequency AC waveform on photographic paper. The equipment handles 6 transducers simultaneously and data from 96 separate channels.

With loudspeakers mounted on each side of a fuselage test specimen, as shown in Figure 14, sound pressure levels inside the cabin and cabin wall movements can be measured. The effect of the variation of stiffness and/or damping to remove resonant frequencies or reduce modes whose frequencies cannot be adequately isolated can be explored.

Even when the input noise is fairly uniformly distributed through the spectrum, as with boundary layer or jet noise, 'colouration' by the structural modes is significant but, in this case, damping is the only effective treatment. Also internal soundproofing is not very effective in suppressing low frequency propeller noise and here again the structural response must be reduced.

DATA GATHERING AND REDUCTION

In all forms of modern testing, whether on the ground or in flight, the method of gathering detail data by simple clocks, scales and weighing machines is rarely adequate. This has brought into existence many new miniaturized instruments, some of which have been previously mentioned. The ease with which large numbers of these can be employed (sometimes extravagantly) has overloaded manual methods for recording and reduction of data thus leading to mechanical processes.

Instrumentation engineers now have at their disposal a wide range of transducers of resistive and reactive types able to withstand severe environments. The availability of consistent transistors with which to build small volume, high power amplifiers is a great asset.

The dominant consideration is to plan a co-ordinated system to produce processed information at a high rate. There is a close analogy between recording systems and the data store of a computer with similar scope for dispute on the rival merits of digital and analogue methods. It can be agreed however that visual presentation of data is mainly only an editing guide.

All data reduction by machinery will, however, remain imperfect. Human judgment must still apply corrections for random and systematic errors in the instrumentation. The capacity of a machine is no greater than a host of men having the prime qualification of infallibly correct arithmetic.

CONCLUSION

Those who served in drawing offices 20 years ago can recall the modest scale of equipment aids that were sufficient to develop the military aircraft of the last war.

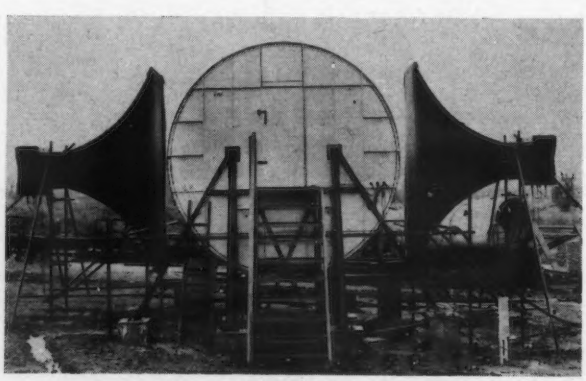


Figure 14
Acoustic specimen and exciters on site

A few designers had yet to be persuaded that a wind tunnel was really essential outside research establishments. Structural testing was confined to spasmodic selection of isolated parts followed by relatively crude destruction tests on major components. Most of the checks were left to post constructional stages.

When the chance arises to inspect aircraft of that era, we realize that the engineering standards were comparatively uncomplicated and that sophistication was only beginning to emerge. Yet designers of that or of any earlier time were no less able than those of today, nor were the risks accepted by test pilots any the less.

As the store of knowledge has grown, so records have been broken, not only by specially built aircraft but often by adapted operational types, to be equalled but little later by standard versions. In making these strides experts have waxed and textbooks have waned. Learned institutions and conferences have flourished. Perhaps the least satisfactory feature of recent circumstances is the restricted role of the individual. If a specialist, he and his group must be content with localized knowledge with rare opportunities of entering deeply into others' problems. Those lacking special qualifications make little headway without instruction. The few with wide responsibilities must needs watch and listen to the experts, we hope with broad if not minute understanding, inevitably delegating much to others' trusted skills, attending to the wood rather than to the trees.

How different this is from the past when one could direct the pruning of each branch and all could grasp the full intent and purpose. There must be many who, on occasions, reflect on the more personal sense of achievement enjoyed by Wallace Rupert Turnbull.

ACKNOWLEDGEMENTS

I am grateful for the help and advice of many of my colleagues in the preparation of this Lecture, especially Mr. J. Hahn, Head of the Mathematical Services Group, Mr. H. S. Liner, Assistant Chief of Structures Design, and Mr. E. R. Arbon, Head of Engineering Development Laboratories.

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THE EFFECT OF ICING ON AIRCRAFT EQUIPPED WITH VORTEX GENERATORS†

by A. D. Wood* and D. G. Gould**

National Aeronautical Establishment

SUMMARY

By reproducing in plastic the ice formation which has been found to build up on vortex generators tested under heavy icing conditions in a low temperature wind tunnel, it has been possible to carry out flight tests to determine the effects of such icing on vortex generator installations on a Harvard and on a CF-100 aircraft. From these tests it has been found that for an installation of delta-shaped, co-rotating vortex generators mounted well forward on the wing, icing of the generators has only a very small effect on the stalling speeds and no adverse effect on aircraft handling near the stall. Any increase in drag which occurs as a result of vortex generator icing is small and insufficient to be a cause of concern.

INTRODUCTION

In recent years, vortex generators have been applied to the wings and other surfaces of various high subsonic and transonic aircraft in order to alleviate certain adverse effects resulting from shock-induced separation. As a result of some theoretical and flight investigations carried out by the Flight Research Section and completed in 1956, a particular vortex generator configuration was recommended for the CF-100 aircraft. This configuration produced the greatest improvement in aircraft buffet boundary with the least drag increment. The arrangement consisted of co-rotating and sharply swept delta blades set at an angle of attack of 10° and distributed along the full span of the wings at 9% of the wing chord and continuing up the sides of the nacelles. This arrangement is shown in Figure 1.

On a number of occasions some concern has been expressed with regard to the possible effects of an ice accumulation on a vortex generator arrangement of this description. Since the range of ambient temperatures conducive to heavy airframe icing is small (0°C to −10°C) and since a jet aircraft of this type will obtain considerable protection from kinetic heating of the airframe at high speeds, the only circumstances under which significant airframe icing is likely are those which may occur during protracted flight at low speed and low altitude, such as during a ground controlled approach. If icing of the vortex generators does occur, however, it is of interest to know whether the characteristics of the aircraft, particularly the stalling speeds, handling qualities at the stall and the drag at low speeds, are adversely affected.

†Received 7th August, 1958. National Aeronautical Establishment Report LR-220.

*Head, Flight Research Section.

**Associate Research Officer, Flight Research Section.

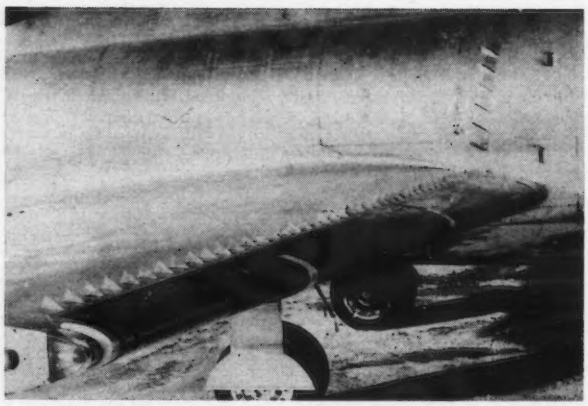


Figure 1
CF-100 Mk. 4 aircraft fitted with vortex generators

To resolve this question the Flight Research Section undertook a series of flight tests in which the condition of vortex generator icing was reproduced. This report describes these experiments and the results obtained.

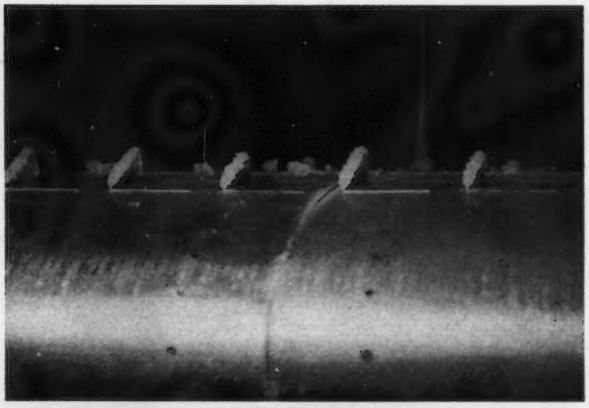
SIMULATION OF ICE FORMATION

Several of the vortex generators were supplied to the Low Temperature Laboratory where they were installed on a section of wing in a manner corresponding approximately to that on the CF-100. Several runs were then carried out in the icing wind tunnel. Ice was allowed to accumulate on the generator blades up to a maximum amount beyond which there was a tendency for the ice forward of the leading edge of the blades to break off. The typical form of the ice accretion is illustrated in Figure 2. This formation was considered to be representative of the worst case likely to be encountered during prolonged exposure in low speed flight.

To preserve the contour of this ice formation a coat of melted paraffin wax was applied to the surface. By allowing the ice to melt a thin wax envelope of the ice formation was obtained and supplied to the Flight Research Section.

From the wax envelope so obtained a set of plastic reproductions was made by the procedure outlined in the Appendix, so that a complete set of vortex generators was available with the experimentally determined ice formation closely represented (Figure 3).

From this and other figures it should be noted that the most characteristic feature of the ice formation is



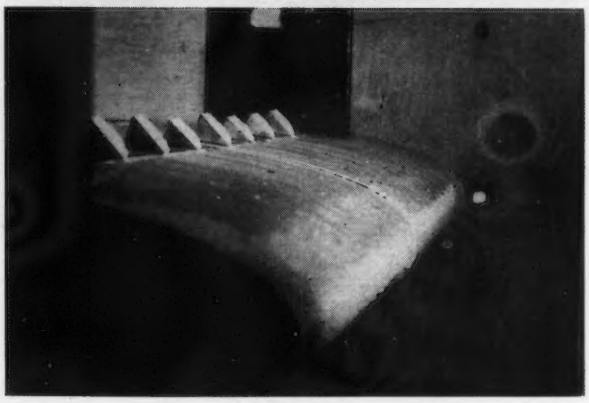


Figure 2
Typical ice formation obtained during wind tunnel tests

an accumulation along the leading edge extending forward into the stream and widening into a comparatively flat surface normal to the stream. An additional build-up of ice occurs on the "lower" surface of the generator blade and takes the form of series of horns extending forward and downward from the trailing edge.

FLIGHT TESTS

Since the wind tunnel tests were not designed to give information on aerodynamic effects on the wing, the flight experiments were carried out in stages. The

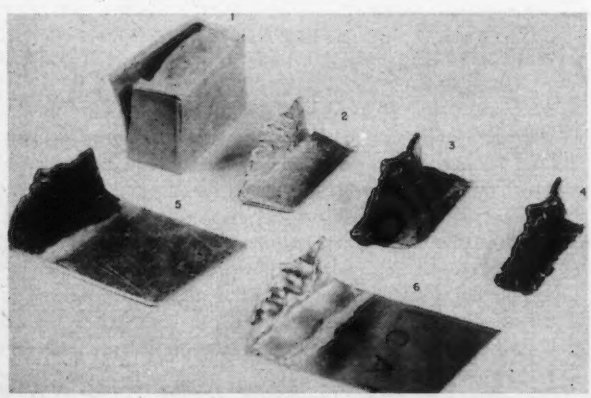


Figure 3
Method of reproducing the ice formation in plastic (see Appendix)

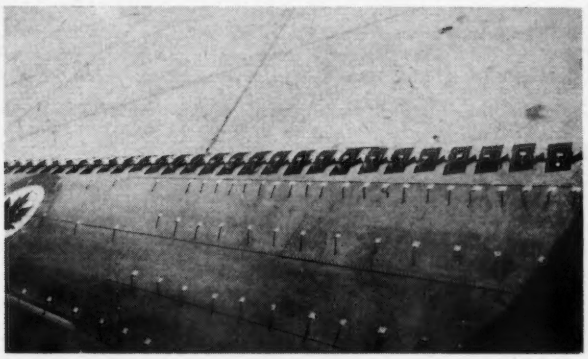


Figure 4
Vortex generators with simulated ice formation on Harvard aircraft

generators were first applied to a Harvard aircraft; extending over approximately the inboard third of the span on the first flight, extending past the inboard end of the ailerons on the second flight, and finally applied across the entire span. On the Harvard the vortex generators were mounted at a local angle of attack of 20°. This large angle of attack, together with the relatively large ratio of generator height to wing chord, compared with that for the CF-100 represented a more severe case than that to be expected during the subsequent tests on the CF-100. The entire upper surface of the port wing of the Harvard was tufted so that any unusual flow behaviour near the stall could be noted (Figure 4).

On the first flight it was found that the presence of the "iced" generators was scarcely detectable. As the generators were extended across the span, there was a tendency for the stall to originate inboard in a more pronounced manner than in the case of the clean aircraft, so that the handling characteristics at the stall, particularly lateral control, were noticeably improved. The tuft configuration during a typical stall is shown in Figure 5, which indicates the extent of inboard separation prior to flow breakdown near the wing tips. Better lateral control was also obtained during high speed stalls. No measurable differences in the stalling speeds either with the flaps and wheels down or up were detected. No attempt was made to determine the change in drag, but any change which did occur was not noticeable to the pilot.

Figure 5
Typical stall of the Harvard with "iced" vortex generators showing the extent of inboard separation

TABLE 1

COMPARATIVE STALLING SPEEDS AT 10,000 FT CORRECTED TO 31,300 LB ALL-UP WEIGHT

	Configuration	Indicated Stalling Speed ≈ Knots
Aircraft Without Vortex Generators	Wheels Up Flaps Up rpm 60%	115
	Wheels Down Flaps Down rpm 80%	102
Aircraft with Generators Plus Simulated Icing	Wheels Up Flaps Up rpm 60%	115
	Wheels Down Flaps Down rpm 80%	105

A similar procedure was followed using the CF-100 Mk. 4 aircraft. Generators were first applied to the inboard portions of the wings and sides of the nacelles. Stalls were carried out with wheels and flaps up and down at 20,000 ft and 10,000 ft. Repeat flights were made with the generators extended beyond the inboard end of the ailerons and with generators mounted along the entire span with the exception of the regions immediately adjacent to the wing tips. In all cases the handling characteristics of the aircraft at low speeds remained essentially unchanged from those of the basic aircraft without vortex generators. With wheels and flaps up there was little or no rolling tendency at the stall. With wheels and flaps down a wing dropped at the stall. In both cases this behaviour is normal for the aircraft without generators. Comparative stalling speed measurements are given in Table 1. The CF-100 fitted with the "iced" generators is shown in Figure 6.

In the case of the Harvard, it has been noted already that there was a tendency towards a more positive initiation of the stall on the inboard portion of the wing as a result of adding the vortex generators. The fact that a similar tendency was not noticeable in the case of the CF-100 is attributed to the difference in the angle of attack and the orientation of the generators in the two installations. Whereas on the CF-100 the generators were set at an angle of attack of 10° with the circulation producing an inboard force, those on the Harvard were oriented in the opposite sense at 20°. With the latter arrangement the wing boundary layer on the fuselage side of the most inboard generator is unfavourably affected.

CONCLUSIONS

From the laboratory and flight tests described in this report, the following conclusions are drawn:

(a) For an installation of delta-shaped co-rotating vortex generators mounted well forward on a wing, a heavy accretion of ice can be expected to form on the generators under conditions conducive to normal airframe icing.

(b) The effect of generator icing on the stalling speeds of the Harvard and CF-100 aircraft is very small and there is no adverse effect on handling characteristics near the stall.

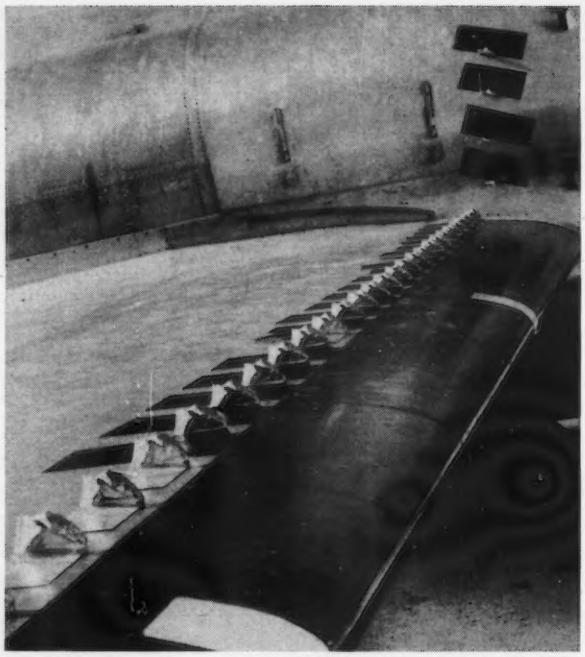


Figure 6
Vortex generators with simulated ice formation on CF-100 Mk. 4 aircraft

(c) Any increase in drag which occurs as a result of ice accumulation on the vortex generators is insufficient to be a cause of concern.

(d) The foregoing conclusions may be expected to have a more general applicability to other aircraft but not necessarily to other vortex generator configurations.

ACKNOWLEDGMENT

The authors are indebted to Mr. J. J. Samolewicz and Mr. C. K. Rush of the Low Temperature Laboratory for the tests carried out in the wind tunnel and to Mr. J. Edwards of the Flight Research Section for his assistance in preparing plastic reproductions of the ice formation. The authors wish to thank the Director, N.A.E., for permission to publish this paper.

APPENDIX
SEQUENCE FOLLOWED IN PREPARING PLASTIC REPRODUCTIONS OF THE ICE FORMATION

Figure 3 illustrates the sequence of operations involved in preparing the plastic reproductions from the original paraffin wax envelope.

(1) Cold setting flexible polysulphide rubber mould after forming on the paraffin wax original.
(2) "Cerrobend" casting from the rubber mould.
(3) The same casting coated with a pigmented polyester resin with glass flock added.
(4) Polyester resin shell with "Cerrobend" melted out.
(5) Polyester resin shell foamed in place on vortex generator blade using a urethane foam.
(6) Completed reproduction with finishing coat of aluminum paint.

THE APPLICATION OF ANALOGUE COMPUTERS TO GUIDED MISSILE DESIGN†

by W. S. Kozak*

Canadian Westinghouse Company Limited

INTRODUCTION

THE guided missile, a prime example of advanced systems engineering, would not have reached its present state of development without comparable advancements in many branches of science and technology. Where certain areas of technology have lagged they have received special effort to bring them up to levels consistent with the state of the art as a whole. To say that any one field comprising guided missile design is more important than the other would be taking a narrow view of things. This paper's almost overriding concern with the analogue computer's contribution in this regard is not meant to boost its singular importance over the other fields, but, by inference, accentuate the necessity for a full appreciation of these fields for successful analogue simulation. The analogue computer, on account of its inherent capability of providing continuous time solutions to problems in dynamics, is a made-to-order device for the mechanization of complex dynamic systems. Analogue simulation of guided missiles is certainly not new as regards computer chronology. Analogue simulation of guided missiles received its impetus in the development of the German V-2 and was greatly accelerated by the American aircraft industry.

ANALOGUE vs DIGITAL

Before discussing advantages and disadvantages of analogue versus digital techniques, I would like to say a few words on simulation per se. The simulation of a dynamic system in a laboratory is found advantageous from considerations of economy, safety and controllability. The first two features are self-explanatory: it being a costly expedient to test fire missiles for data gathering, and a dangerous one where erratic behaviour is concerned. Controllability simply means the capability of imposing controlled environment and missile characteristics on simulated firings. Both analogue and digital computers have been used in the simulation of dynamic systems. By definition, the analogue computer constrains certain physical variables, such as voltages and shaft angles, to obey relationships analogous to the variables of the physical system being represented. By virtue of this correspondence a one-to-one time relationship with the physical system may usually be mechanized, whence physical hardware may be included in the simulation. Digital computation is essentially a counting process where all mathematical operations are reduced to the basic functions of addition and comparison. In the solution of dynamic problems the variables are quantized over controllable intervals; thus extreme accuracy is possible, being limited only by the counting interval programmed. Therefore an inverse relationship exists between accuracy and speed of operation of digital simulators. For a stipulated accuracy real time operation is not always possible.

In choosing one computer over another, attention must be given three considerations: accuracy, speed and the ease of representing the system. At present, at any rate, the fundamental accuracy of the linear class of analogue computer operations is limited by component tolerances. This may be kept down to one part in ten thousand. When non-linear operations, such as multiplication or division of variables, are considered, the accuracy deteriorates to 1/10%, and to as much as 1% if non-analytic function generation is performed. As stated previously, the accuracy of digital computation is theoretically unlimited. As quite often happens, the speed-accuracy advantages of the two nullify each other and the choice is resolved by the effort and expense involved. A point is soon reached where the number of complex operations required complicates the programming to such an extent that precise digital simulation is impossible. In such cases, simplification of the mathematical model to suit digital operations may render the results meaningless. Additionally, because of the inflexibility of a digital programme, changes in the mathematical model that may be necessitated as a result of solution trends are a major undertaking. Only a small number of foreseeable alternatives may be programmed at the start. The analogue computer mechanization is altered very readily, indicating its usefulness as an engineering tool in feeling out a problem.

From an additional engineering viewpoint, the analogue computer offers superior tangible features in the direct relationship between component functions and the parameters of the physical system. This enables the engineer to more readily bridge the gap between the simulated and the real world.

Recent digital differential analyzers have adopted analogue nomenclature and mechanization; to wit, the digital integrator, servo and multiplier. Indications are that the differential analyzer of the future will be a hybrid. Using the digital computer to provide accurate

†Paper read at the Annual General Meeting of the C.A.I. in Toronto on the 27th May, 1958.

*Section Engineer, Computer Laboratory, Air Armament Engineering Dept.

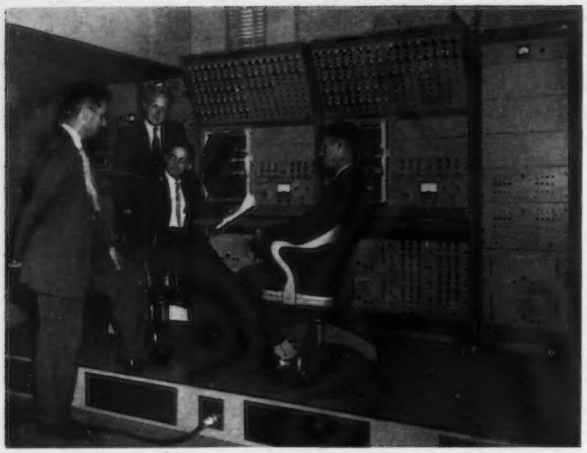


Figure 1
Typical medium-size analogue computer

Figure 2
Typical medium-size digital computer

solutions at discrete points in time, and the analogue computer to fill in the gaps, borrows the best features from both types. For the specific application of missile simulation, the digital computer solves for the slowly varying variables of the problem requiring accurate answers, such as the flight-path trajectory, and the analogue computer processes the faster acting parameters, such as the response of the missile.

By way of concluding these comparisons, Figure 1 shows a typical medium-size analogue computer installation. To be noted are the pre-patch panel containing the problem wiring and the attenuator controls on which problem coefficients are set up.

In Figure 2, the typical digital installation usually contains cleaner lines devoid of manual controls, indicating the relative unalterability of operations once the input data is inserted.

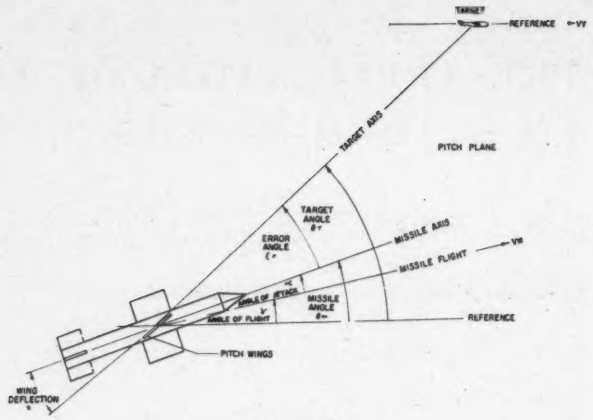


Figure 3
Two dimensional geometry relating an air-to-air missile

CORRELATION WITH TELEMETRY RECORDS

In general, a simulator study of a missile consists of first setting up the mathematical equations of the system, and then programming or mechanizing them, as the case may be, for acceptance by the computer. The next step is the correlation of a limited number of test firings with simulator results. When it is found that computer records do not agree with telemetry records the problem is to determine the source of the discrepancies. These discrepancies may arise either from inaccuracies in the mathematical model or effects of approximations and linearizations that may have been applied to reduce some of the more complex relations. Once test firings have been duplicated on the simulator, excellent prediction of performance under untried conditions is possible on the simulator. If the missile should then prove to be unstable under certain conditions, various stabilizing techniques may be examined on the computer. Once an optimum configuration is determined it may be included in a missile for evaluation in an actual test firing. Besides effecting a saving in economy, such a technique provides a clear analytical picture of the problem.

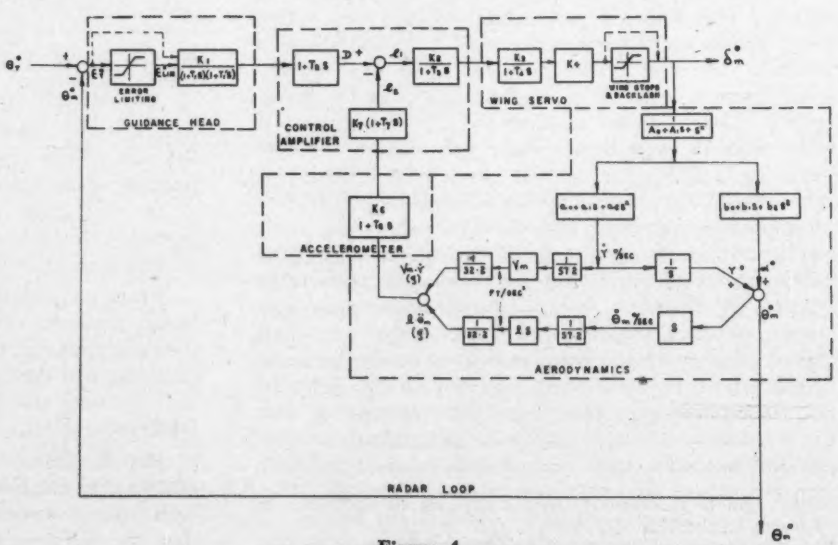


Figure 4
Block diagram of missile functions in 2-D

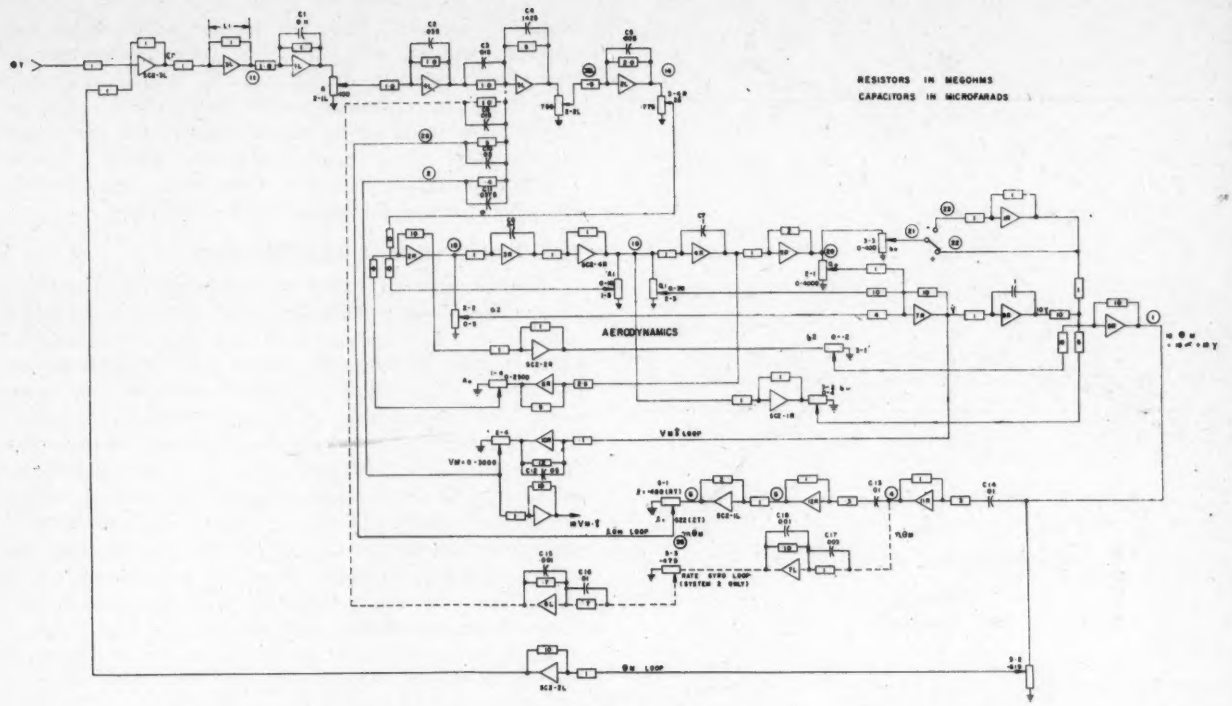


Figure 5
Corresponding analogue diagram

STABILITY STUDIES

Perhaps the most basic application of analogue computers is the determination of missile stability and response when treated as a closed loop servo system. Figure 3 illustrates the two-dimensional geometry of an air-to-air missile, and defines the external parameters. For purposes of a stability study the target is assumed to be at infinite range, hence target data is not required. The input to such a servo system is target angle θ_T, and the loop is closed by the radar loop which compares missile angle θ_M with target angle θ_T. As in standard servo methodology transfer functions are used to describe the missile elements and are inserted into a block diagram of the form shown in Figure 4. The corresponding analogue diagram of this system is shown in Figure 5. System gain margin and weathercock frequency may be determined by the simple expedient of turning up the gain of the major loop as at point 11. The amount this gain has to be increased to just sustain oscillations, with no input, is a measure of the gain margin. If initially unstable, the degree of instability is determined by the reverse process of gain reduction.

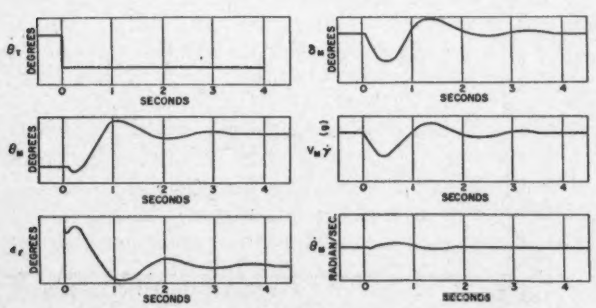
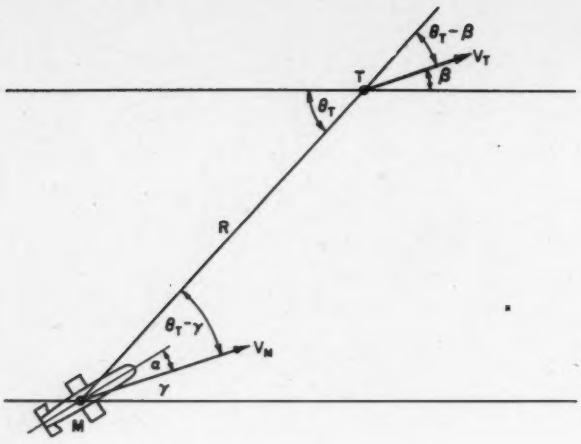


Figure 6
Simulated dynamic performance

Using this method for stability determination, a tolerance study may easily be effected. To determine the worst possible combination of gain and time constant tolerances of the various component blocks contributing towards instability, each parameter is adjusted in turn to its upper and lower tolerance limits, and the stability trend noted. A consideration of n components necessitates $2n$ tests.

Following stability investigations, response characteristics may be obtained from the same analogue set-up. Inputs are applied to the simulated guidance head corresponding to target angle, θ_T. Voltages at various points in the analogue may be recorded to yield dynamic performance characteristics as shown in Figure 6. Reading down, on the left, are voltages corresponding to: target angle, attained missile angle, which approaches θ_T in the limit, the error angle between the two; and, on the right, the average deflection angle of a pair of wings, missile lateral acceleration, and the rate of change of missile angle. Recordings indicating poor performance necessitate an optimization programme. An initial paper and pencil analysis would indicate the likely areas for improvement. A computer evaluation permits a rapid cut-and-try variation about analytically-derived values for rapid optimization. This applies to main systems elements which may include the airframe as well as stabilizing and shaping network constants. The necessity for a high-speed method of computing stability and performance is readily appreciated when it becomes necessary to optimize over a large range of velocities and altitudes.



$$\dot{R} = V_T \cos(\theta_T - \beta) - V_M \cos(\theta_T - \gamma)$$

$$R\dot{\theta}_T = V_M \sin(\theta_T - \gamma) - V_T \sin(\theta_T - \beta)$$

Figure 7
2-D kinematics

In a typical study of an air-to-air missile a total of 35 runs were necessitated every time a new component was altered, this resulting from 7 speed and 5 altitude levels.

TWO-DIMENSIONAL TRAJECTORIES

Now a simple stability study is insufficient to give much of a picture of actual missile performance against a target chase. A trajectory or miss-distance study is the next step. To the missile simulation is added the equations of the missile-target kinematics. These, together with the describing vector diagram, are shown in Figure 7. Target and missile velocity vectors are resolved parallel and perpendicular to the line-of-sight *M-T* resulting in the two kinematic equations. Missile velocity is not now considered a constant, but made to vary according to the thrust and drag forces acting on the airframe. Effects of altitude changes manifest themselves in varying coefficients in the aerodynamic portion of the simulation. In addition to these two variables, effects on trajectory may be studied by varying such quantities as initial heading error, boresight errors, antenna errors, blind range, variation in guidance gain and target manoeuvre. In addition to recording missile dynamic responses of Figure 6 an *x-y* recorder plots the relative trajectory:

$$R \sin(\theta_T - \gamma) \text{ vs } R \cos(\theta_T - \gamma)$$

A representative trace is shown in Figure 8. Obviously a prime parameter of interest is the miss-distance which may be obtained either on the *x-y* recording or from a strip chart recording similar to that of Figure 6, if one of the channels were set to record the range *R*. Actual miss-distance may differ slightly from minimum range insofar as the specific fuze pattern of the missile is considered.

2-D trajectories also permit of the investigation of proposed navigational laws or intended navigational computers. For an air-to-air missile three basic navigational systems exist. These are: pursuit, proportional, and constant bearing, with variations. The mathematics of these basic systems are rather well known. For any system, simple relationships exist between the target-to-missile error angle, or its rate-of-change, and the resulting actuating signal transmitted to the missile controls. Written in transfer function form these equations are easily mechanized for study on the computer.

THREE-DIMENSIONAL TRAJECTORIES

The ultimate study is in three dimensions. In addition to revealing certain phenomena not existent in the single plane case, 3-D studies provide the analyst a truer picture of spatial performance. These other phenomena are the effects of missile roll, radar cross-talk and target noise. The simpler class of missiles are quite often roll-rate stabilized to circumvent the necessity for expensive free gyros. This, at any rate, has been considered economical in some circles. A small amount of rolling is therefore tolerated. Computer studies disclose required characteristics of roll-rate gyros for compromise between resulting spiralling of missile trajectories which result from cross-talk and high roll-rates, and erratic behaviour at low. Radar cross-talk exists to some measure in front end receivers. It is often required to determine the maximum spill-over from one microwave receiver channel to another that may be tolerated.

Target noise results from such causes as target vibration and orientation producing a random apparent direction, from a mean value, of the radar target. This would be simulated on an analogue computer by means of a low frequency noise voltage added to the computed bearing angle and mechanized to vary statistically according to programmed instructions. To evaluate effects of noise adequately, a large number of trajectories must be taken under similar initial conditions to permit a statistical evaluation of the results. That only computer-derived trajectories are economical is an obvious statement.

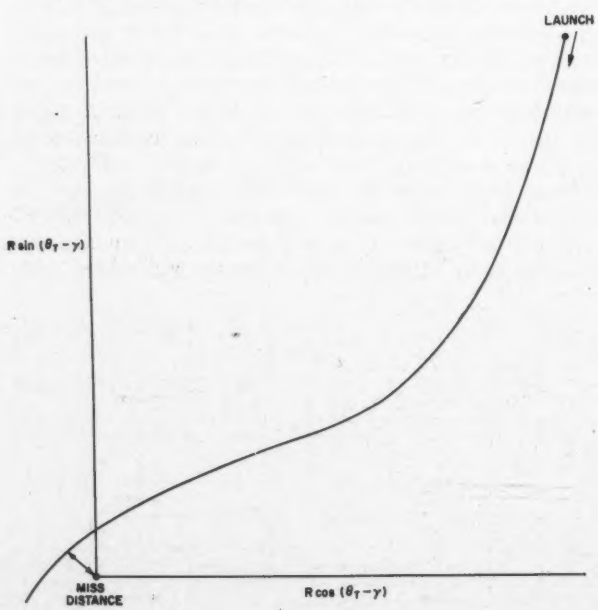


Figure 8
Typical 2-D trajectory

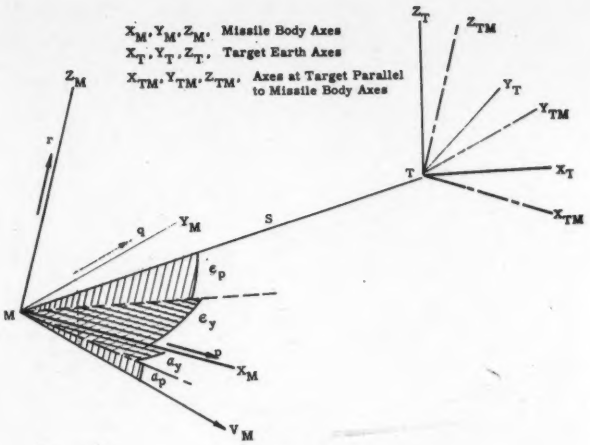


Figure 9
3-D geometry

However, a 3-D study is only undertaken after the single-plane case is thoroughly exhausted because of the multiplication of the potential sources of system malfunction, and the increased complexity resulting.

Four basic methods exist for representing 3-D missile kinematics. These are: Euler angles, direction cosines, quaternions and a linearization method that takes advantage of small angle approximations. The latter method results in a considerable saving in equipment for a slight loss in theoretical accuracy. After linearization a total of 18 differential and algebraic equations results. This should be compared with the two equations for the 2-D case. Figure 9 illustrates basic 3-D geometry. It should be noted that full graphical representation involves several more vector diagrams not included which take into account such things as co-ordinate transformation, translation and rotation arising from rolling motions of the missile. Nevertheless, for purposes of illustration, resulting equations of Figures 10 to 13 inclusive are included. Figure 10 shows the three equations for the velocities of the target co-ordinate axes with respect to missile body axes. These are written in Cartesian coordinates as $\dot{x}_{TM}$, $\dot{y}_{TM}$, $\dot{z}_{TM}$. p, q and r are missile roll-rates about the three principal axes: roll or longitudinal, yaw and pitch. S is missile-to-target range; V_M is missile linear velocity; the α's are angles of attack, p referring to pitch and y to yaw; and ϵ is error angle. Now, rolling of the missile causes an apparent change of the target as seen by the missile. This is equivalent to a rotation of the target axes in the opposite direction. Such a condition results in the three sets of three equations shown in Figure 11. The first set relates target angular velocity, the second set, target linear velocity, and the third, target acceleration, to the new coordinate system. Figure 12 shows the three equations defining resolved missile velocities $\dot{x}_M$, $\dot{y}_M$, $\dot{z}_M$, and Figure 13 the linearized trigonometric relations and range rate, $\dot{S}$. The analogue of a complete 3-D system is not included on account of spatial restrictions.

PHYSICAL SIMULATION

Portions of actual missile components may be tested for compatibility in the overall system by their inclusion

$$\dot{x}_{TM} = -V_M - S \begin{vmatrix} q & p \\ \epsilon_y & \epsilon_p \end{vmatrix}$$

$$\dot{y}_{TM} = V_M \cdot \alpha_y - S \begin{vmatrix} r & p \\ \epsilon_p & 1 \end{vmatrix}$$

$$\dot{z}_{TM} = V_M \cdot \alpha_p - S \begin{vmatrix} p & q \\ 1 & \epsilon_y \end{vmatrix}$$

Figure 10
Velocities of target coordinate axes w.r.t. missile body axes

$$\frac{d\omega_x}{dt} = \begin{vmatrix} \omega_y & \omega_z \\ q & r \end{vmatrix}$$

$$\frac{d\omega_y}{dt} = \begin{vmatrix} \omega_z & \omega_x \\ r & p \end{vmatrix}$$

$$\frac{d\omega_z}{dt} = \begin{vmatrix} \omega_x & \omega_y \\ p & q \end{vmatrix}$$

TARGET ANGULAR VELOCITIES

$$\frac{dV_{Tx}}{dt} = \begin{vmatrix} V_{Ty} & V_{Tz} \\ q & r \end{vmatrix}$$

$$\frac{dV_{Ty}}{dt} = \begin{vmatrix} V_{Tz} & V_{Tx} \\ r & p \end{vmatrix}$$

$$\frac{dV_{Tz}}{dt} = \begin{vmatrix} V_{Tx} & V_{Ty} \\ p & q \end{vmatrix}$$

TARGET LINEAR VELOCITIES

$$\dot{V}_x = \begin{vmatrix} V_{Ty} & V_{Tz} \\ \omega_{Ty} & -\omega_{Tz} \end{vmatrix}$$

$$\dot{V}_y = \begin{vmatrix} V_{Tz} & V_{Tx} \\ -\omega_{Tz} & \omega_{Tx} \end{vmatrix}$$

$$\dot{V}_z = \begin{vmatrix} V_{Tx} & V_{Ty} \\ \omega_{Tx} & \omega_{Ty} \end{vmatrix}$$

TARGET ANGULAR ACCELERATIONS

Figure 11
Equations resulting from missile roll

$$\dot{x}_M = \dot{x}_{TM} + \int_0^t \dot{V}_x \cdot dt + V_{Txo}$$

$$\dot{y}_M = \dot{y}_{TM} + \int_0^t \dot{V}_y \cdot dt + V_{Tyo}$$

$$\dot{z}_M = \dot{z}_{TM} + \int_0^t \dot{V}_z \cdot dt + V_{Tzo}$$

Figure 12
Defining equations of resolved missile velocities

$$\epsilon_p = \frac{z_M}{S}$$

LINEARIZED TRIGONOMETRY

$$\epsilon_y = \frac{y_M}{S}$$

$$\dot{S} = \dot{x}_M + \dot{y}_M \epsilon_y - \dot{z}_M \epsilon_p$$ RANGE-RATE

Figure 13
Range rate and trigonometric equations after linearization

into appropriate points of the simulated system. In this category the analogue computer may provide signal input for missile amplifiers and servos, or through auxiliary apparatus operate missile control surfaces, or actuate an hydraulically operated flight table in a mock-up of flight conditions. In the first role, missile components are included for two reasons; firstly, to check recordings of performance with the physical component as an integral part of the loop to determine performance of the component, and secondly, to ascertain the validity of the transfer function representation of the component. However, inserting a piece of apparatus into a simulator loop simply for the sake of eliminating the tedium of setting up a precise mathematical description of the component is a mistake in that no real understanding of the system is obtained. It is understood that the inclusion of hardware into a simulator loop necessitates operation in real time.

In this category is included an important test technique which utilizes tape recorded telemetry data as input signals into simulated loops. The correlation of output recordings vindicates the fidelity of the simulation.

An important application of analogue computers is in the check-out of a missile at various phases of its manufacturing or pre-flight stages. When thus included, it is an integral part of a missile Overall Test Set. One such O.T.S. manufactured by Westinghouse for checking out the late Velvet Glove missile is shown in Figure 14. The various electronic racks contain power supplies, test equipment and recording apparatus, as well as analogue computer gear. In the left foreground is the missile under test, with its front end enclosed in a microwave anechoic chamber. Hydraulic pressure, supplied by

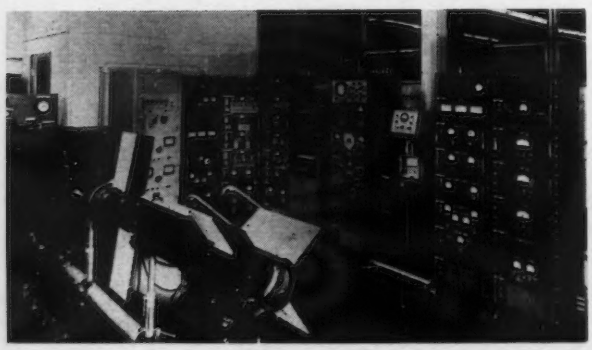


Figure 14
Canadian Westinghouse manufactured Overall Test Set

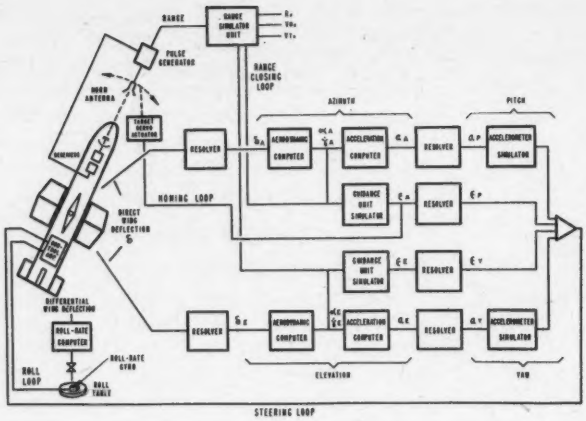


Figure 15
Block diagram of the O.T.S.

pumps and a reservoir not shown in the illustration, actuates missile wings, a target antenna, and a roll table. This table, located in the third rack from the right, provides angular motions for check-out of missile roll-rate gyros. Simulated target and missile flight conditions are provided by the aerodynamic, acceleration and kinematic analogue computers. Computed signals may be fed into the missile by a check-out plug on the missile airframe, and the loop responses recorded for simulated trajectories.

Figure 15 shows a block diagram of the O.T.S. Microwave signals are supplied to the rear and front channels of the missile microwave receiver, having a frequency, pulse width, and pulse repetition frequency equal to that normally received in flight. The amplitude and delay interval between the two signals is controlled by the Range Simulator to represent different ranges. The signal to the front antenna is emitted from a horn radiator situated approximately 1 meter in front of the missile dish. This horn is capable of horizontal movement, its position being controlled by an electro-mechanical servo actuator. The deflection of missile wings due to the presence of a target error signal is detected by means of the internal wing potentiometers. DC potentiometer signals are used directly to the steering loop channels, and differentially to the roll loop. The steering loop provides signals for operation of the wings through the missile control amplifier. The roll loop provides signals for control of a roll table for the purpose of providing angular accelerations to roll gyros and accelerometers. A homing loop provides signals to a servo actuator that rotates the target antenna in a horizontal plane actuated by negative missile-target error signals. A range closing loop accepts missile attitude signals and together with initial range and velocity values computes instantaneous missile-to-target range. This signal adjusts the separation between two pulses generated by a pulse generator; a direct pulse feeding the missile receiving antenna through the horn antenna, and a delayed pulse feeding the rear-channel microwave receiver. Coincidence of these pulses is the condition for a direct hit. Provisions exist for the injection of disturbance signals and the monitoring of analogue voltages at various points in the

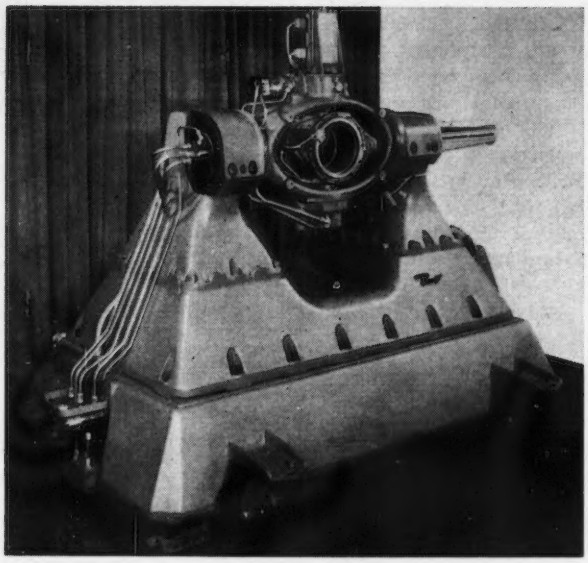


Figure 16
Bendix 3-axis flight table

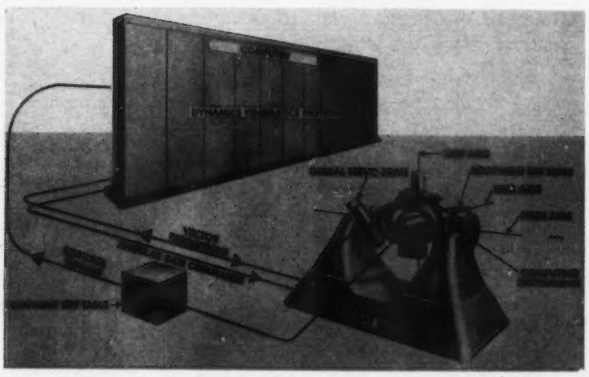


Figure 17
Block diagram of the Bendix flight table

system. If so desired the O.T.S. may also be used as a closed loop simulator with the exclusion and simulation of all missile hardware.

Another class of items developed for physical simulation includes flight tables and altitude simulators. The flight table provides for the evaluation and testing of control, stabilization and guidance equipment under the influence of angular motion of motion-sensitive missile components. These tables may be of either the single axis or three-axis variety. A table manufactured by the Bendix Aviation Corporation is shown in Figure 16. The various hydraulic and electrical lines are brought in through the gimballed swivels via rotating joints. A table such as this one may hold such components as guidance heads, accelerometers and gyros, being restricted only by its maximum load capabilities. The simplified block diagram of a system including the flight table is shown in Figure 17. The analogue computer in the background computes the 3-D kinematics of the target and missile systems, and transmits angular rate commands to the

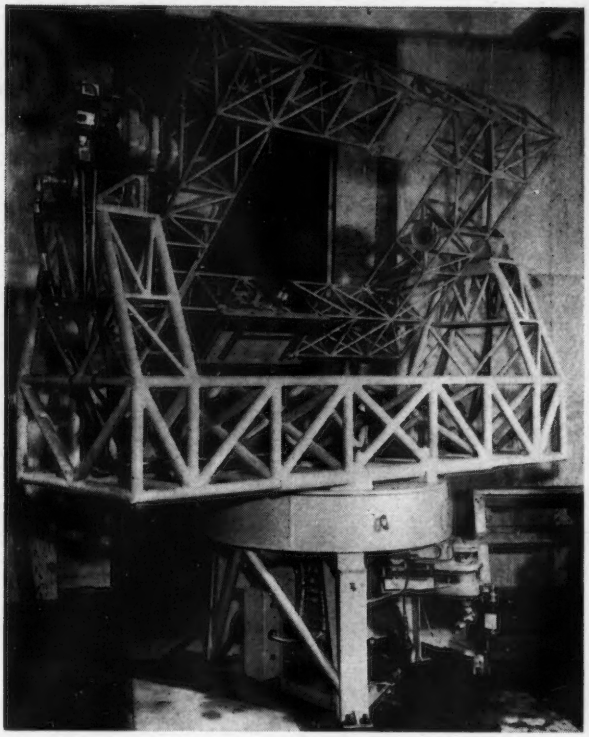


Figure 18
Aircraft Armament's 3-axis flight table

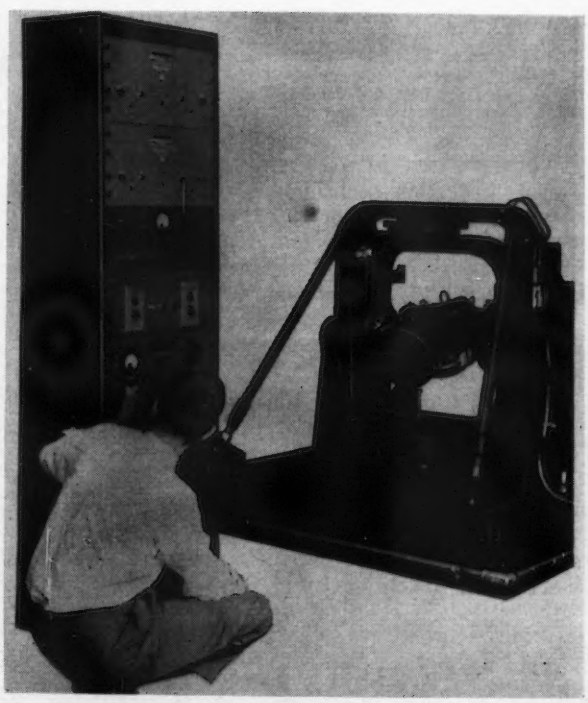


Figure 19
California Technical Industries' 3-axis flight table

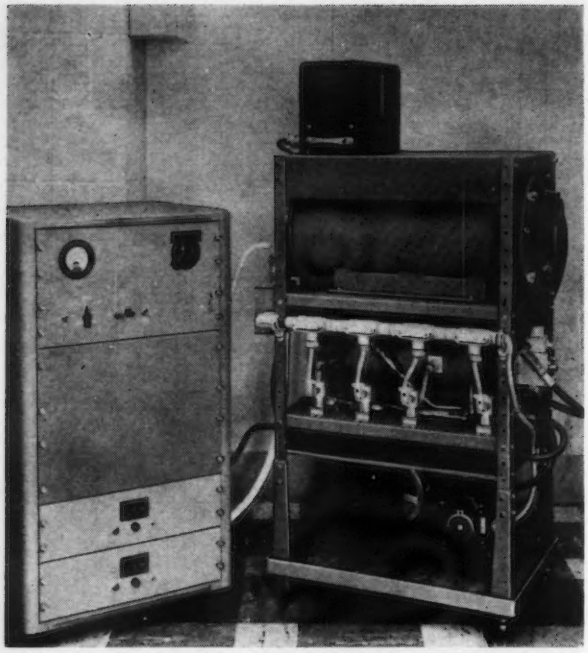


Figure 20
California Technical Industries' altitude simulator

flight table velocity servos. Electrical signals resulting from component accelerations are picked-off and fed back into the computer as control signals. Coordinate transformations are required between the computer and the flight table as in the O.T.S. A slightly different construction is employed in the yoke structure of the Aircraft Armament's flight table shown in Figure 18. Still another version is shown in Figure 19. This was originally developed by Westinghouse in Baltimore and is now being manufactured by California Technical Industries.

Still another piece of apparatus is an altitude simulator manufactured by the same firm, illustrated in Figure 20. Barometric pressures are varied in an enclosed cylinder under analogue computer command signals, made to vary according to computed altitudes encountered along flight trajectories. Thus characteristics of pressure sensitive transducers and their effect on missile system performance may be determined.

CONCLUSIONS

In conclusion, some indication of the areas requiring further investigation in the future is warranted. These general areas appear to be three in number: firstly, the necessity for more data gathering in three dimensional trajectories; secondly, for large missiles at any rate, the effects of missile elasticity and bending; and thirdly, the characteristics and effects of noise.

FILM LIST

The Institute is engaged in the preparation of a concise List of aviation films for the use of its Branches and Sections and by other organizations interested in obtaining films on aeronautical subjects. The work is being undertaken in collaboration with the Air Industries and Transport Association and the Canadian Owners and Pilots Association and, therefore, the List will include films on flying training, meteorology, and other aspects of aviation, as well as engineering.

Several lists of aviation films are already available, but they include a great deal of obsolete material and they probably omit many interesting technical films, held by research organizations and the like, which might be procurable by special arrangement for showing to restricted and qualified audiences. Furthermore, it is not possible to classify films intelligently from the titles and brief descriptions usually given in these lists. Consequently any consolidation of the existing lists would contribute nothing; the proposed List must be based upon first-hand reports.

Since it is clearly impractical to set up a Selection Committee to review, assess and classify all the films which might be of interest, all members of the Institute are asked to cooperate in this work. Any member having personal knowledge of a film which, in his opinion, would be instructive or of current interest to an aviation audience is asked to send particulars to the Secretary of the Institute.

To ensure that the particulars reported are those needed in the listing, a special report form or "check sheet" has been prepared; these forms are available from the Chairmen of Branch Programmes Committees and from C.A.I. Headquarters.

SOME PROBLEMS IN AIRLINE TURBINE TRANSPORT OPERATION†

by R. J. Baker*

Trans-Canada Air Lines

THERE is really nothing new in this paper I am presenting today on some of the operational problems which we are encountering now and may expect in airline turbine transport operation. It is only an attempt to gather together some of the more pertinent problems which we feel are associated with these new turbine-engined aircraft and discuss them in light of our present knowledge.

It has been said frequently that the turbine transport aircraft is just another new airplane to the operator – some of the same old familiar pieces arranged a little differently and some new ones added. Experience only will indicate whether or not we now have the correct solutions to new problems in mind. The length of time here will not permit us to go into any great detail but it might be interesting to briefly review some of these problems involved in handling the new aircraft from ramp to ramp around the world.

AIRPORTS

Due to the higher takeoff weight to payload ratio of the turbine aircraft, particularly the jet, we have again taken the easier way out by demanding higher takeoff and landing speeds and consequently longer runways. It seems unfortunate that this is so but until the VTOL concept materializes to a successful standard of operation and economics, it appears that the pilot must be asked again to shoulder the responsibility of added speed during takeoff and landing and the country the cost of the runways. The cost of airport and runway development to around 10,000 ft or more for the large jets is so high that figures seem to lose their meaning. Canada's program involves some $75,000,000 over the next period, with much of this going to runway extensions. There should be no runway strength problem since the tire loadings of even the largest jets are comparable to present aircraft.

Asphalt runways, taxiways and ramp areas give trouble due to kerosene spillage, which means that future surface construction should be of some other material, especially at any ground holding points. All the rules in the world will not prevent some degree of spillage.

We all feel that terminal space and facilities at our major airports is inadequate, although plans are being made and construction is in progress. Since a large turbine aircraft will easily carry 140 people, one can visualize the ticketting, catering, baggage handling, customs and transportation problems at our major airports in the near future. We must plan for it and whether we are planning fast enough is a question.

The airport noise problem is one with which we are all concerned. Airports must of necessity be kept close to the cities they serve and suburban communities invariably grow up around them. Power means noise and the scream of the turbine-engine compressor and jet blast can be intolerable. This problem must be faced squarely and not with the back door approach of "educating" the public, who will eventually arise en masse with their protests. The ultimate objective, of course, is to maintain thrust with no drag loss and no noise – a worthy objective but one which must be modified by compromise in all three respects. Considerable experimental work has been done in the U.S. and U.K. on noise suppression, concentrating mainly on that due to jet exhaust.

It would help if we could determine the human tolerance of noise, particularly jet noise on takeoff, and if we could determine what the acceptable decibel level is for normal living – that which can be tolerated and that which cannot be tolerated. This is a very complex problem and difficult to analyze.

Around the airport and on the ramp the propeller noise for normal operation can be about the same for the turboprop as for piston engines. However, the shrill scream of certain types of compressors can border on the intolerable and care must be taken by maintenance people to position turbine aircraft for run-up checks to avoid compressor noise disturbance as much as possible. Figure 1 illustrates a typical ground noise field pattern of a Viscount with which we are all familiar. It indicates the very general overall noise level distribution of compressor, propeller and exhaust. This became a serious problem in the residential area around Winnipeg Airport, the TCA main Viscount maintenance base.

The noise on takeoff of the turboprop is not troublesome but the straight jet can be very much so. Much development work has been done on tail pipe noise suppression. A figure of 105 db at 500 ft of altitude on takeoff has been used by some as a desired maximum level for suppression design. Jet exhaust noise is caused by the resulting turbulence when the jet exhaust mixes

†Paper read at the Mid-season Meeting of the C.A.I. in Vancouver on the 27th February, 1958.

*Flight Test Engineer-Pilot.

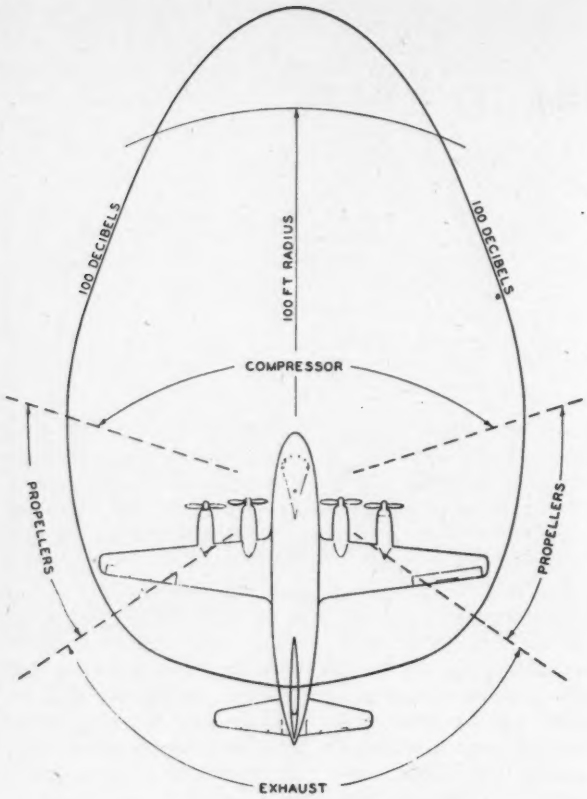


Figure 1
Viscount ground noise field pattern — 4 engines, 9,500 rpm (propellers, 1,000 rpm)

with the atmosphere and is of varying intensity and frequency. A by-pass engine with its slower moving gases is slightly quieter than a straight jet of the same thrust rating. In any engine the noise will be reduced if the mixing rate is accelerated and the speed of the exhaust jet relative to the surrounding atmosphere is reduced rapidly. Figure 2 illustrates the Rolls-Royce suppression nozzle, the corrugations of which give mechanical mixing of air and gas. A secondary flow of air through the corrugations into the exhaust promotes still further mixing and reduces the drag to some degree. It is hoped that such suppression devices will reduce the jet noise level to acceptable values without decreasing thrust to any marked degree. On the Conway engine, for example, the noise reduction is in the order of 5 db — a considerable reduction, with a decrease in thrust of 1¾% at takeoff power. There will undoubtedly be a maintenance penalty. The overall weight penalty may not be as great as might be expected because reduced noise may require less soundproofing and alleviate other troubles due to acoustical vibration.

GROUND HANDLING

Since the capital cost of the larger turbine aircraft is high by past standards, turn-around time on the ground must be minimized to avoid unproductive capital investments. While maintenance time is important, it is the few minutes lost here and there which can add up to an unproductive total. The ground handling equipment and ramp equipment, such as tow tractors, power units, refuelling, air conditioning and de-icing units, must be adequate in size, manoeuverability and in simplicity of operation to keep the turn-around or through time at the ramp to a minimum. For example, at the present time on Viscount aircraft, it requires in practice almost all of the allotted twenty minutes to fill the fuel tanks. Aircraft like the DC-8, which carries 18,000 gals, will require fuelling equipment of high flow rates. This is obviously more important in turbine-engined aircraft because of the higher fuel requirements and is of greater importance in the straight jet as compared with the turboprop. The present tentative plan is for fuelling deliveries of 1,200 gals per minute through four hoses attached to hydrant outlets on each side of the aircraft.

The Viscount is not a large aircraft but it requires for its turboprop powerplant starting an electrical power unit capacity of 1,500 amperes at 28 volts peak load. Marginal ground power units can result in wet starts and overheats. The large jet engines require an air starting capacity of 40 lb/start, obtained from a storage system, either tank or separate self-propelled truck. Gas turbines can be used with the turbine driving a generator to provide electrical power and a bleed-off to provide air for starting; they have a disadvantage in that they are very noisy.

We all know the difficulties encountered in de-icing aircraft of the present in the typical ground icing conditions encountered in this country. We use messy de-icing fluids, load and depart from hangars, use heated hangars to melt ice — all accompanied by attendant costs and delays. These troubles will be magnified with the larger turbine aircraft.

For an aircraft the size of the DC-8, ground conditioning units must have a capacity of 200 lb of air per minute at 45°F at a pressure of 12 inches of water to provide cabin cooling 15°F below a hot day ambient temperature. The ground heating unit must have a capacity of 400,000 BTU.

FLIGHT PLANNING

Proper flight planning is perhaps the largest single factor affecting the economics of turbine operation. While it has been important with piston-engined aircraft, its importance is magnified with turboprop and straight jet.

As an illustration of proper or improper flight planning in terms of fuel and time, Figure 3 illustrates the

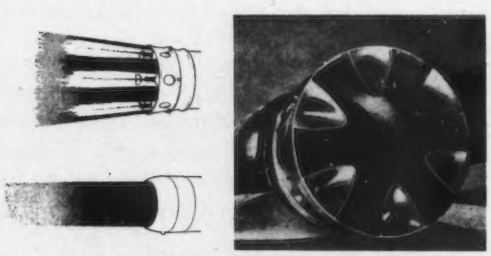


Figure 2
Rolls-Royce noise suppression nozzle

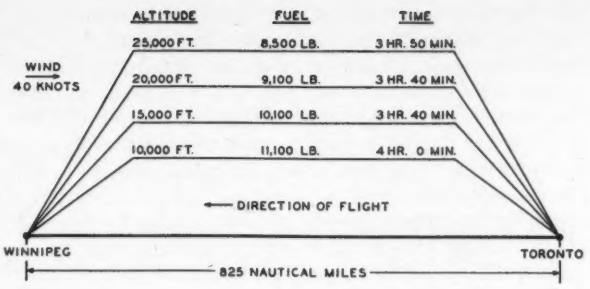


Figure 3
Viscount flight planning — altitude, fuel and time
Toronto — Winnipeg

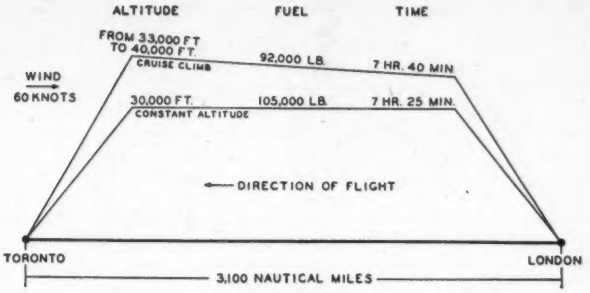


Figure 4
DC-8 flight planning — altitude, fuel and time
London — Toronto

effect on both over the Toronto-Winnipeg route with the turboprop Viscount. Note the difference in time and fuel consumed using four altitudes under standard conditions and the same wind.

Maximum range is obtained on a turbojet by increasing the altitude as the flight progresses and thus the speed until the Mach number for drag divergence is attained. Figure 4 illustrates the effect in time and fuel over the London-Toronto route of the DC-8 with Conway engines, using different types of flight plans.

It will be realized that the economics of the operation can be quite seriously affected by not flight planning to the optimum. Fuel consumed can affect payload, or if payload is not affected for the particular conditions and load available, operating cost is affected by time required, since aircraft are maintained and flight crews paid on a time basis. We have evolved in TCA a tabular system to aid in flight planning the Viscount. This is simply pre-computed flight plans over a range of altitudes, temperatures and winds for each route leg and enables the optimum to be selected in terms of time or fuel required. Figure 5 is an extract from one of these charts. The optimum flight plan procedure is obtained by scanning the chart. Similar types of procedures can be used on the new aircraft.

Flight planning of course is materially affected by air traffic control and its limitations. It is of little value to carefully flight plan for the optimum and then have to carry additional fuel or plan extra time to allow for possible deviations from the optimum. Particularly for the straight jet, the narrow range of operational altitude makes it imperative that flight planning be precise and within the limitations of the other operational variables.

TRANS-CANADA AIR LINES

FUEL REQUIREMENTS CHART

RESERVE 2,500 LBS.
INSTR. APPROACH 600 LBS.
HOLDING 2,200 LBS/HR

TYPE A/C VISCOUNT MILEAGE 825 N.M.

TIME & FUEL CONSUMED TEMP. STANDARD

6C

Y Z · W G · Y Z

ALT. TEMP.	AVG. T.A.S. KNOTS	WIND COMPONENTS–KNOTS 0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
25000		3:18	3:21	3:25	3:29	3:33	3:37	3:41	3:46	3:51	3:56	4:01	4:07	4:12	4:19	4:25	4:31	4:38	4:46	4:54	5:02	5:11
-35	265	7290	7410	7560	7690	7840	7990	8150	8310	8490	8660	8850	9050	9260	9470	9700	9940	10200	10460	10750	11050	11360
24000		3:15	3:19	3:22	3:26	3:30	3:34	3:38	3:43	3:47	3:52	3:57	4:02	4:08	4:13	4:20	4:26	4:33	4:40	4:47	4:55	5:04
-33	269	7350	7490	7620	7760	7890	8050	8210	8370	8540	8720	8920	9120	9310	9520	9750	9990	10240	10500	10760	11060	11370
23000		3:13	3:16	3:20	3:23	3:27	3:31	3:35	3:40	3:45	3:49	3:54	3:59	4:04	4:10	4:16	4:22	4:29	4:35	4:43	4:51	4:59
-31	272	7440	7570	7700	7840	7990	8140	8300	8460	8630	8810	9000	9200	9400	9620	9830	10070	10320	10570	10850	11140	11470
22000		3:11	3:14	3:18	3:21	3:25	3:29	3:33	3:37	3:42	3:46	3:51	3:56	4:01	4:07	4:12	4:19	4:25	4:32	4:39	4:46	4:54
-29	274	7580	7700	7840	7990	8140	8300	8450	8610	8780	8970	9150	9360	9560	9780	10010	10240	10500	10760	11020	11320	11650
21000		3:10	3:13	3:17	3:20	3:24	3:28	3:32	3:36	3:40	3:45	3:50	3:55	4:00	4:06	4:11	4:18	4:24	4:30	4:37	4:45	4:53
-27	275	7700	7830	7970	8120	8260	8420	8580	8750	8920	9100	9300	9500	9720	9930	10170	10430	10660	10920	11200	11500	11820
20000		3:09	3:12	3:16	3:19	3:23	3:27	3:31	3:35	3:39	3:44	3:49	3:54	3:59	4:05	4:10	4:17	4:23	4:29	4:36	4:44	4:51
-25	276	7850	8000	8130	8290	8430	8600	8750	8940	9120	9300	9500	9700	9920	10130	10380	10630	10870	11150	11450	11740	12060
19000		3:08	3:12	3:14	3:19	3:22	3:26	3:30	3:34	3:39	3:44	3:48	3:53	3:58	4:03	4:09	4:15	4:21	4:28	4:34	4:42	4:50
-23	277	8020	8160	8310	8460	8610	8770	8940	9120	9300	9500	9680	9900	10120	10360	10570	10830	11110	11390	11670	11920	12310
18000		3:07	3:11	3:12	3:18	3:21	3:25	3:29	3:33	3:38	3:43	3:47	3:52	3:57	4:02	4:08	4:13	4:20	4:26	4:33	4:40	4:48
-21	278	8180	8310	8460	8630	8790	8940	9120	9300	9490	9680	9880	10100	10300	10530	10790	11000	11300	11600	11900	12200	12520
17000		3:06	3:10	3:13	3:17	3:20	3:24	3:28	3:32	3:36	3:41	3:45	3:50	3:55	4:00	4:06	4:11	4:18	4:24	4:31	4:38	
-19	279	8350	8490	8650	8810	8970	9130	9300	9490	9680	9890	10090	10300	10530	10770	11010	11270	11550	11840	12150	12470	
16000		3:05	3:09	3:12	3:16	3:19	3:23	3:27	3:31	3:35	3:40	3:44	3:49	3:54	3:59	4:05	4:10	4:17	4:23	4:30		
-17	279	8550	8690	8850	9000	9170	9350	9520	9710	9910	10120	10330	10550	10770	11030	11270	11550	11830	12130	12440		
15000		3:09	3:12	3:16	3:19	3:23	3:27	3:31	3:35	3:40	3:44	3:49	3:54	3:59	4:05	4:10	4:17	4:23	4:30			
-15	274	8700	8850	9010	9130	9360	9540	9720	9920	10120	10340	10550	10800	11040	11300	11560	11840	12140	12460			
14000		3:11	3:15	3:18	3:22	3:26	3:30	3:34	3:39	3:43	3:48	3:53	3:58	4:04	4:09	4:16	4:22	4:29				
-13	269	8830	8990	9170	9340	9520	9700	9900	10100	10320	10530	10780	11020	11280	11540	11820	12120	12440				
13000		3:14	3:17	3:21	3:25	3:29	3:33	3:37	3:42	3:47	3:52	3:57	4:03	4:08	4:15	4:21	4:27					
-11	265	8960	9120	9290	9480	9660	9860	10070	10270	10500	10730	10970	11220	11480	11770	12070	12380					
12000		3:16	3:20	3:24	3:28	3:32	3:36	3:41	3:46	3:51	3:56	4:02	4:07	4:14	4:20	4:26						
-9	260	9130	9300	9500	9690	9870	10080	10270	10510	10750	10970	11250	11520	11780	12100	12400						
11000		3:19	3:23	3:27	3:31	3:35	3:40	3:45	3:50	3:54	4:01	4:06	4:12	4:19	4:28							
-7	256	9240	9420	9620	9800	10020	10220	10430	10670	10920	11170	11430	11720	12020	12320							
10000		3:21	3:25	3:29	3:34	3:39	3:43	3:48	3:53	3:58	4:04	4:10	4:16	4:23								
-5	252	9400	9600	9780	10080	10200	10410	10630	10880	11110	11400	11660	11970	12270								
9000		3:22	3:26	3:31	3:36	3:40	3:45	3:50	3:55	4:00	4:06	4:12	4:18									
-3	251	9600	9790	10010	10200	10410	10640	10880	11130	11390	11670	11950	12250									
8000		3:24	3:28	3:33	3:38	3:42	3:47	3:52	3:57	4:03	4:09	4:15										
-1	247	9780	9970	10180	10380	10630	10860	11120	11350	11610	11930	12210										
7000		3:28	3:33	3:38	3:42	3:47	3:52	3:57	4:03	4:09	4:15											
+1	242	9970	10170	10390	10620	10840	11120	11350	11620	11920	12220											
6000		3:32	3:37	3:41	3:46	3:51	3:56	4:02	4:08	4:14												
+3	237	10200	10410	10640	10890	11120	11400	11650	11940	12250												
5000		3:32	3:37	3:41	3:46	3:51	3:56	4:02	4:08													
+5	237	10380	10600	10830	11080	11330	11590	11880	12180													

HEADWIND (left) HEADWIND (right)

Figure 5
Viscount flight planning chart

AIRCRAFT TYPE	V_2 TAKE-OFF SPEED KNOTS	1.3 V_{SO} APPROACH SPEED KNOTS
DC-3	80	75
NORTH STAR	108	103
DC-6	113	103
SUPER CONSTELLATION	122	112
VISCOUNT	114	110.
DC-8	158	132

Figure 6
Comparison of takeoff and approach speeds

FLIGHT OPERATION

In operating the new turbine-engined aircraft we have two basic characteristics, neither of them new — higher speed and higher altitude. Higher speed means faster thinking and better decision-making aids; higher altitude presents no new problems in itself except for decompression and emergency procedures to cope with it. Due to aerodynamic improvements the flying of the aircraft en route can be easier and less fatiguing.

From the start of the takeoff roll we as pilots are faced with higher operating speeds. V_1 and V_2 speeds are higher in the desire to carry the largest possible load and faster. The penalty for this, as stated before, is greater pilot responsibility and longer runways. As a pilot, it was my fervent hope years ago that industry could have gone the other way sooner in developing high lift devices for takeoff and landing, but we are not doing so in the present and planned turbine aircraft. Figure 6 illustrates how takeoff and approach speeds have increased.

Increase in takeoff speed has resulted in the demand for a go/no-go instrument to help the pilot in assessing acceleration prior to a decision to continue or abandon the takeoff. Some of the military operations have established runway markers as an aid in this. Some thought will indicate the problems in either marker or instrument concept. I would only point out here that such a device is demanded by operators because the decision time in terms of runway distance covered is extremely limited due to the higher takeoff speeds. At a V_1 speed of 120 kts the distance covered in a decision-reaction time of four seconds is 830 ft.

Handling characteristics of turboprop aircraft with their relatively low Mach numbers do not differ materially from the piston-engined types. Engine acceleration is good in all phases, including baulked landing. Propeller reversing for reduction of landing roll is available on some types. Advantage is taken of the finer blade angle necessary for starting to decrease landing roll by the additional drag due to propeller and compressor windmilling. In the Viscount this braking effect amounts to about 250 ft under standard sea level conditions at landing weight.

En route operation of the turbine-engined aircraft is straight forward and simple and should be well within the capabilities of two properly trained pilots. Powerplants are easier to set up to pre-determined data and the aircraft systems are no more involved than present systems. Experience in the past has indicated the need for better flight compartment design and it is unfortunate that we have not always used that past experience to advantage. Airplanes could be made simpler, easier and safer to operate if we only applied our knowledge in this growing industry. It is disconcerting to see some of the design or lack of it in the future transports. In spite of this, operational procedures can be simpler than with current piston types. The flight crew can be provided with pre-computed data to enable optimum powerplant settings for the conditions of operation. Flight crews operating turbine engines must be fully aware of the new concept of fuel consumption and the variables that affect it. The crew of a large transport are running a big business and their qualifications, experience and training must be adequate for the job.

Weather presents essentially the same problems as we have had in the past, although design knowledge has increased weather capabilities. For example, in TCA piston-engine operation pilots are somewhat wary of asking a Viscount pilot what ice he has encountered because the answer is usually "very little, if any". This is because design knowledge has been incorporated in the Viscount so that it can handle easily the normal icing encountered en route on both airframe and powerplant. This does not mean the Viscount pilot can become complacent about icing because he can easily lose thrust through improper control of the powerplant de-icing system. If it is not noticed that ice is forming and the electrical de-icing equipment is not operated soon enough, sufficient ice will form on the intake cowling so that when it is released by de-icer operation or descent into warm air it can slide into the engine, resulting in a flame out. The engine can fortunately be relit. We all know of similar problems on other aircraft due to ice accretion. There are various schemes involving compressor bleeds and electrical heating to combat turbine powerplant ice. The point I would like to make here is that although ice is still a problem with the turbine engine, it can be alleviated by proper design and operation of anti-icing or de-icing equipment.

Heated leading edges of one type or another are and can be used successfully to combat airframe ice. We can sum up the icing problem by saying that design and operating experience is adequate to face it. There has been some thought that de-icing equipment can be dispensed with on the high, fast airplane but we would suggest caution in following along with this concept. De-icing equipment is expensive but airplanes and people more so and ice formation is not a problem which can be viewed with complacency. It is true that ice is more prevalent in the lower levels and although the high altitude jet will be relatively free of ice in cruising flight, the turboprop will operate in icing levels in cruise and both types must climb through and descend under traffic control conditions where they will be in ice formation for some periods of time at least.

Hail can be troublesome in the turbine aircraft due to damage of leading edges, fillets, radar domes and any

other exposed structural surface. The hail problem is accentuated due to the higher speed and it will be necessary to slow the aircraft down with airbrakes or other drag devices to an acceptable speed to avoid damage.

Turbulence is also accentuated with the higher speed. The high altitude clear air turbulence can be encountered without warning. There has been some investigation into this with a view to a warning indication of some kind; the carrying of passengers at high altitude may accelerate the program. Speed brakes will be used for quick deceleration and for high rates of descent at slow airspeed through the more turbulent lower levels.

At the present time there is considerable discussion in regard to reverse thrust devices on the landing roll and whether their use will be allowed in certification and operation for landing runway lengths. The turboprop can use propeller reversing, or at least, like the Viscount for example, drag is automatically increased when the propeller goes into a finer pitch on touchdown. Any sort of propeller reversing device on a turboprop is similar in its general operation and results to those on present piston-engined aircraft. Reverse thrust on the straight jet is required to a greater degree and, at the same time, is more of a new problem. There have been various types of thrust reversal units developed, all designed to reverse the direction of engine thrust at the jet pipe. Figure 7 illustrates a thrust reversal unit developed by Rolls-Royce for use on their Conway engine. Deflector vanes operated by a pneumatic ram directs the gas stream in a forward direction. It will be interesting to view the development of reverse thrust devices, their maintenance problems and whether their use will be allowed in certification.

Handling characteristics of the larger jet transport types can be somewhat different. The effects of swept wing design may lead to aerodynamic problems, such as dutch roll and lateral control considerations, unless compensated for in the early design stage. We hope simplicity will not suffer. Somewhat confusing to some of us is the difference in concept of power versus full manual control design. We recognize the designer's problem in providing for proper control throughout the speed range; we can only hope that for simplicity and cost of maintenance and safety the high speed jet transport can be operated satisfactorily without complete dependence on power controls.

NAVIGATION

Turbine powered aircraft alter the navigational concept mainly because of their higher speed and operating altitude.

On a time basis, reporting points can be farther apart to decrease the communication contacts and crew work load. High altitude VOR airways will be designed with co-channels 500 – 550 miles apart to provide a static free system and avoid channel interference. Surveillance radar, which will be in full operation on this continent within the next two years, will assist in position fixes on or off airway routes. Maximum advantage of radar is only attained with some form of transponder equipment.

On over-water or off-airway long range routes, navigation time is critical so that running fix accuracy, as we know it now, becomes difficult due to the increased speed. There are various types of newer aids under investigation and trial, such as Doppler, Inertial systems, Decca and Dectra, and it is likely that some agreement will be reached on their use. The Doppler system offers promise and has been specified by most operators. It can provide wind information to a high degree of accuracy and will be extremely helpful in upper air wind forecast and flight planning. The general accuracy is ±1% of the distance travelled and ±½% in drift angle. The use of free gyro compass systems and grid navigation is now possible and further improvement in such navigational equipment will be of benefit in attaining a basic heading and track reference. The initial setting of a free gyro is the major problem, with a desired accuracy of ½ to 1°. It must be checked by astronomical reference or other navigational fix. Distance information on climb and descent will be of advantage with turbine power. Particularly on descent, it will give the pilot and Air Traffic Control a guide for more efficient aircraft operation and traffic handling.

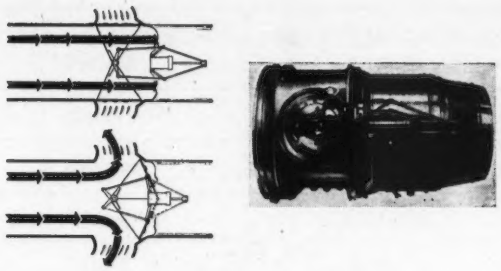


Figure 7
Rolls-Royce thrust reversal unit

COMMUNICATION

The air to ground communication facilities do not seem to offer any new concepts except the ever-increasing problem of congestion. VHF communication, with its static-free advantages, can be improved by widespread ground satellite systems. Long range HF communication has the static precipitation, aurora and skip difficulties, although precipitation static will be alleviated to some degree with high flying transports. Selective calling, more efficient use of frequencies available and common control can alleviate some of the present congestion, which assumes more importance at the higher speeds of the turbine transports.

TRAFFIC CONTROL

We discussed previously the importance of flight planning and aircraft operation on the economics of the airline. The traffic control problem on climb, en route cruise and approach is equally as important. In fact, the flight planning must be tailored to the traffic control requirements to a major degree.

We hear much these days of the inadequacies of our present air traffic control systems. A great deal of study has been done on the problem and it is a most difficult one. It is so easy to criticize but so difficult to offer a solution in this case.

We know that the rapidly increasing traffic density at all altitudes by military and civil aircraft will be fur-

HOLDING ALTITUDE FT.	FUEL FLOW – 4 ENG. LB./HR.
S.L.	11,600
10,000	10,200
20,000	9,200
30,000	8,600
36,000	8,600

Figure 8
Fuel flow for holding — DC-8

ther magnified as more turbine aircraft come into operation. The turbine engine, particularly the straight jet, cannot hold efficiently in traffic at the lower altitudes. We need better navigational facilities, radar scanning, machine calculation and accounting to avoid the human error, and improved communications networks.

The present basic concept for turbine aircraft is that they will be held as far as possible at high altitude, in the case of the jet above 20,000 ft due to high fuel consumption at lower altitudes, as indicated in Figure 8 for the DC-8. When clearance for approach is given they will be released to descend rapidly around 4,000 ft/min from their holding point. Fortunately, this is possible because of their high degree of pressurization necessary for cruising flight. There should be no passenger discomfort on descent.

Figure 9 indicates the difference in fuel consumed of a DC-8 using different descent techniques and procedures and is just an example of the importance of the procedure used and the ultimate effect of the traffic control system in the descent phase. It is probable that corridors will be established to facilitate a straight-in approach.

Various committees, national and international, civil and military, have been set up to study the air traffic control problem for en route flight and terminal areas. Operators and state administrations must first reach agreement on the objectives and then set up the means to attain these objectives on a standardized basis throughout the world. All concerned recognize that it is a major factor in the safety and economy of the airlines, military and other operators. The problem is not a new one confined to turbine-engined aircraft but is accentuated be-

DESCENT FROM 35,000 FT.

LONG RANGE DESCENT			HIGH SPEED DESCENT		
FUEL	TIME	DISTANCE COVERED	FUEL	TIME	DISTANCE COVERED
LB.	MIN.	NAUT. MI.	LB.	MIN.	NAUT. MI.
1,500	24	130	1,900	17	130

Figure 9
Comparison of descent procedures — DC-8

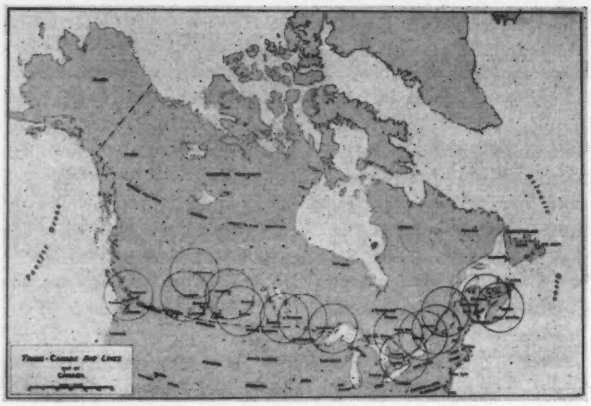


Figure 10
Planned Canadian airport and airways surveillance radar

cause of the increasing numbers, increased speed and somewhat different operational requirements of these newer types. The basic questions asked at these traffic control meetings are such as: "What type of flow control system will prevent collisions and traffic jams? How can routes be fitted together, paralleling and crossing? How can traffic be controlled in and out of terminal areas?" Fixed block assignment providing lateral and vertical separation en route is used now. There would appear to be a large number of blocks available depending on the separation, but the difficulty even today is that the pressurized piston-engined transports all desire altitudes within a relatively narrow range. Turboprop and straight jets are even more restricted and inflexible. Modern planned radar control with identifying transponder beacons from the aircraft will help in narrowing the block assignments and preventing collisions. The computation and allotment of blocks must be rapid, with virtually no time lag in air-ground communication. It is difficult to separate flights by pre-arrangement, due to weather and other unforeseen contingencies.

It would appear that over continental areas at least, radar control, passed from one area to another with identifying signals on the scopes, offers the only immediate possibility for controlling en route traffic from takeoff to final approach. Figure 10 indicates radar surveillance coverage in Canada planned over the next two years on the trans-continental routes.

The final approach and landing of turbine aircraft, while not exactly a traffic control problem, is closely allied to it because of the possibility of a missed approach and implications of proceeding to an alternate with high fuel flows at low altitudes. The landing phase is the finale of the whole system; it must be efficient and safe when used to its maximum capability or the whole traffic control system is made ineffective. The straight jet in particular is economically committed to land in starting its descent. The pilot must know exactly what the ceiling and ground visibility will be before he makes the decision to descend. With present aids, the probability of a missed approach with a jet is higher due to higher approach and landing speeds. It is simply a question of time versus human and mechanical judgment and reaction.

To land an aircraft in low weather requires more than a radio system; it is a complex problem of pilot psychology, coupling methods and final visual references made more complicated by the higher speed of the turbine transport.

Radio approach systems are being improved and the newer microwave concept offers more stable directional and vertical guidance. The method used to couple the aircraft to the landing system becomes important. Automatic coupling, with control through the autopilot, will reduce the time lag and aircraft response but any such systems must remain fully operative and closely monitored. Psychologically, the pilot looks for visual reference in the final phase and it must be in a reliable, standardized form to aid in the flare-out. It would appear as if pictorial displays are not yet practically possible. To summarize, it would appear as if reliable, fully automatic approach couplers will be the first means to allow lower approaches in low ceiling and visibility conditions. Radar monitoring will assist in reducing pilot anxiety and provide added safety. Completely zero-zero landings at the high approach speeds of turbine transports for everyday scheduled operation appear farther away; it looks like a long development period and it is a question which will be reached sooner, its solution or the VTOL concept, to provide complete safety, schedule regularity and economic relief in reduced fuel requirements.

METEOROLOGICAL

Meteorological forecast requirements for the turbine-engined aircraft are somewhat different and more exacting that at present. Due to high velocity jet streams, upper air wind forecasts above 20,000 ft must be reasonably accurate. For example, with the DC-8, an average forecast error at 35,000 ft of say 20 kts on an Atlantic crossing means 4,000 lb of fuel or conversely that loss in payload. Percentage-wise the effect of wind on these high speed aircraft is not as great as it is with present slower piston-engined types. En route temperatures can be critical in some jet operations if the engine power on a hot day is insufficient to climb the airplane up to the same cruise altitude as on a standard day. Terminal forecasts must be more positive and weather more accurately measured so that descent can be commenced or decision made to proceed to the alternate. Weather authorities throughout the world are working on these problems of weather forecast and measurement and it is hoped that improvement in this field will be forthcoming.

CONCLUSION

In concluding this paper, I would again say that nothing really new has been presented but only an attempt made to highlight what we recognize as some of the problems facing us in this industry within the next few years. The challenge is great and interesting; the solutions are ours.

SPECIAL ANNIVERSARY MEETING

QUEEN ELIZABETH HOTEL

MONTREAL

23rd and 24th February, 1959

C.A.I. LOG

SECRETARY'S LETTER

TEEING OFF

THE CAI season starts with the Montreal Branch Golf Tournament held this year on the 22nd August. I put in an appearance at the Dinner in the evening and, though I cannot vouch for the Golf, I can say that the Dinner, in itself, is worth attending. The prize-giving ceremony conducted by Messrs. Chadborn and Conrath, the traditional master-minds of this annual affair, is terrific.

I am sure that his many friends outside the Montreal Branch will be very pleased to know that an E. B. Schaefer Memorial Trophy has been introduced. Mr. Schaefer, who died in July, was always a strong supporter of this event and he was no mean performer; he was the Tournament Champion last year.

The Tournament was held at the St. Andrews Country Club, which is situated on a promontory at the confluence of the Ottawa and North Rivers. Mr. Richmond and Mr. Stephenson made history by arriving by water, in what they called a "yacht"; a "Past-Presidential Barge" woud be a more dignified term.

BADDECK AGAIN

Our plans for a memorial of the first flight in Canada, which we shall unveil at Baddeck next year, are proceeding apace. At the end of August we received permission from the Department of Northern Affairs and National Resources to erect the memorial in the grounds of the Alexander Graham Bell Museum (not in the Lagoon as formerly thought, but elsewhere) and I made a visit to Baddeck over the Labour Day week-end to find a site.

After much consultation with members of the Bell family and the citizens of Baddeck, we found a site, settled the wording of the inscription and developed some ideas about the form of monument itself. All this is subject to approval by the Council; so I cannot say more about it now.

The opening ceremony of the First International Congress in the Instituto de Prevision, Madrid. The President of the Asociacion Espanola de Ingenieros Aeronauticos is speaking.

MADRID

I was scarcely back from Nova Scotia before I took off for Spain and the First International Congress in the Aeronautical Sciences. I was in Madrid from the 5th to the 13th September, returning via England.

Some 22 nations took part in the Congress. The delegations from the various countries ranged in size from 1 or 2 members to about 160 (from Spain); Canada was

in roughly the right place in the scale, with 10. The programme included some 47 papers, which in my opinion is too many papers to crowd into one week. Admittedly not everyone is interested in all of them and, with concurrent sessions, no one could have attended all of them; but some keen fellow might have attended 33 – and I warrant that he would have been completely fogged if he had.

I think that the overcrowding of a programme is one of the main reasons for the very poor discussion of the various papers, which seems to be a common weakness nowadays. The meeting in Madrid was no better than our own CAI Meetings in this respect. A technical paper should be the basis for a vigorous critical discussion of the subject in hand but unless the audience has had an opportunity to digest what has been said it is very difficult to get a discussion going. In general, papers should be shorter and delivered at a more leisurely gait, to enable the audience to take them in – this is particularly important when they are subject to "simultaneous" translation, which inevitably lags a little behind the speaker.

And again I take up the sword about slides. Most of the slides shown at Madrid were illegible. One glaring example showed two short equations, lost in the vastness of a white background, in about the same proportion as they would have had if they had been typed in the middle of an ordinary sheet of paper; they could have been five times as large without being too big for the slide.

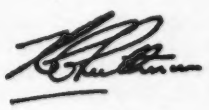
However, our Spanish hosts and the Secretariat of the International Council are to be congratulated on a well run meeting. The international aspects of it made it intensely interesting. There were papers from Spain, France, Great Britain, Belgium, Holland, the U.S.A., the U.S.S.R., Germany, Sweden, Australia and Canada. Such discussion as there was was, of course, addressed into floor microphones and passed through the translators; often the speaker had to don earphones to follow the question, before answering in his own tongue.

The Canadian delegation to the First International Congress: (l to r) G/C E. P. Bridgland (RCAF), Mr. F. R. Thurston (NRC), Dr. H. J. Luckert (Canadair), Mr. J. K. Orlik-Ruckemann (NRC), Mr. J. A. McKillop (Avro), Prof. B. Etkin (UTIA), Mr. J. L. Orr (DRB), Mr. J. A. Chamberlin (Avro) in the doorway, Mr. B. J. Kaganov (Canadair) and Mr. H. C. Luttman (CAI)

Aside from its technical aspects, the Congress afforded a wonderful opportunity to meet old friends and to make new ones. This is by no means the least important feature of all meetings – even our own.

15th SEPTEMBER

Speaking of old friends, I was in London on the 15th September, Battle of Britain Day, and saw the Hurricane and the Spitfire standing in their immortal glory on Horse Guards Parade.



BRANCHES

Montreal

Reported by J. R. Chadborn

Golf Tournament

The Fifth Annual Golf Tournament was held on Friday, August 22nd, at the St. Andrew's Country Club. With the exception of a short rain shower, the weather was fair and seasonable. 76 members and guests played golf and a buffet dinner was served to 83.

W/C C. R. Thompson, Chairman, welcomed the assembly and handed over the proceedings to the writer.

Mr. T. A. Harvie was called upon to introduce the E. B. Schaefer Memorial Trophy. This trophy was donated by a number of close associates at Canadair of the late Mr. Schaefer and will be awarded annually to the player, whether member or guest, who posts the lowest gross score. At the time of his death, Mr. Schaefer was Chief Engineer at Canadair and was well known to CAI members as a golfing enthusiast. This year the trophy was won by S/L M. T. Friedl with a score of 83.

The Bob Wright Trophy remains in the same category (low gross member). Should a member win the E. B. Schaefer Trophy, as happened this year, the Bob Wright Trophy is automatically won by the second low gross score for member and this year it was won by Mr. J. R. Holding with a score of 90.

The Ross Aero Trophy, which is awarded for the lowest gross score posted by a guest, was won this year by Mr. W. Chester with a score of 87.

The tournament was apparently enjoyed by all participants and the buffet style dinner once again proved successful in eliminating lengthy waiting for everyone to sit down.

In closing this report, I wish to thank Mr. R. J. Conrath for his usual sterling support and Mr. D. Stevens who officiated at the starter's table on ticket sales and scoring.

Edmonton

Reported by P. F. Leigh-Mossley

September Meeting

The first meeting of the 1958-59 season was held at RCAF Association 700 Wing at 8.00 pm on the 10th September.

Mr. H. Stapleton took the chair in the absence of our Chairman, Mr. J. Bristow. Mr. Stapleton welcomed the 25 members and 3 guests to the first meeting and then read the Branch's Annual Report and Financial Statement for the year 1957-58, which were adopted as read. He then introduced the Executive for the new season.

Mr. C. C. Young then took the chair and a vote of thanks was proposed and adopted to the outgoing Executive.

Mr. Young then explained the general aims and ideas of the new Executive and the meeting as a whole agreed with them. After the general meeting a film was shown entitled "Vertical Flight".

Ottawa

Reported by R. L. Wardlaw

September Meeting

The first meeting of the 1958-59 season was held on the 12th September at Beaver Barracks. Mr. H. H. Kelland, Chairman, presided over the meeting at which Mr. A. M. Wachs, Chief of Component Design, Sikorsky Aircraft Corp., gave a talk entitled "Turbinizing of the S-62A Helicopter".

The speaker, who was introduced by CDR N. A. Smith, outlined the development problem of converting the S-55 helicopter to a turbine powered version, while at the same time providing it with "omniphibious" characteristics. The speaker emphasized that in spite of the additional weight associated with an omniphibious hull and all-weather capabilities, significant gains in payload cruising velocity and hovering ceiling had been realized. The increased comfort associated with the reduction in level of noise and mechanical vibration was pointed out. Mr. Wachs' talk was well illustrated by a colour film of a flight demonstration by the S-62A.

There were 30 members present and the lively discussion period that ensued indicated their keen interest in this development.

The speaker was thanked by Mr. J. E. Maule.

Halifax-Dartmouth

Reported by Lt. J. A. Turner

September Meeting

The Branch held its first meeting of the current season in the cinema of the Chief Petty Officers' Mess, HMCS Shearwater, on Thursday, 18th September. A total of 35 members and guests were present.

The Chairman, CPO R. L. Sabourin, informed the members of the recent death of CPO P. J. McKenna, who had passed away on the 13th September.

The speaker for the evening, Surgeon Lieutenant-Commander H. D. Oliver, Principal Medical Officer, HMCS Shear-

Presentation of trophies at Montreal Branch Golf Tournament: (l to r) Bob Wright Memorial Trophy — Mr. J. R. Holding (winner) and Mr. J. R. Chadborn; E. B. Schaefer Memorial Trophy — Mr. T. A. Harvie, S/L M. T. Friedl (winner) and W/C C. R. Thompson; Ross Aero Trophy — Mr. W. Chester (winner) and Mr. J. R. Chadborn

water, was introduced by Mr. R. Wallworth.

The speaker, who is a specialist in aviation medicine, presented a very interesting and informative paper on "Toxicity of Aircraft Fuels". In his introduction, LCDR Oliver noted the need for a greater understanding of the potential hazards in handling aviation fuels. Normally, personnel concerned are aware of the fire hazard but have little, if any, knowledge of the potential toxic hazards which may be encountered. To illustrate this point, he gave a brief and general analysis of some of the liquids and solid fuels currently in use indicating the constituents which could have a toxic effect and the physical symptoms which may be induced. In his conclusion he stressed the fact that provided reasonable precautions were observed, the potential hazards from the toxicity of aircraft fuels would be largely overcome.

After a brief intermission, a discussion period ensued during which the speaker answered questions presented by the members and guests. At the conclusion of the period, Mr. T. Howard Rogers of the Naval Research Establishment thanked the speaker on behalf of those in attendance.

Vancouver

Reported by G. W. T. Roper

September Meeting

The meeting was held on the 17th September and was chaired by Mr. R. J. McWilliams. Total attendance was 38 members and 12 guests. A series of films to be shown was announced by the Programmes Chairman, Mr. A. M. Parry, and an expression of thanks on behalf of the membership was given by Mr. McWilliams.

The films shown featured "Seven League Boots", the story of Okanagan Helicopters' widespread operation across Canada; the De Havilland film entitled "50° Below Operations"; and concluded with the Fairey Aviation film which presented "The Preparation for Recording and Actual Recording of the Record-Breaking Flight of the Fairey Delta Aircraft".

There was no discussion or business following the showing of films.

MEMBERS

NEWS

J. C. Floyd, F.C.A.I., presented the fourteenth British Commonwealth Lecture before the Royal Aeronautical Society on the 9th October. The title of his lecture was "Some Aspects of Canadian All-Weather Fighter Development".

A/V/M M. M. Hendrick, F.C.A.I., has recently taken up his new appointment as Chairman, Canadian Joint Staff, Washington.

B. J. Kaganov, A.F.C.A.I., has been appointed Director, Research and Advanced Development, Canadair Ltd.

C. Campbell, M.C.A.I., has resigned from Orenda Engines Ltd. to join Purolator Products (Canada) Ltd. in the capacity of Assistant Chief Engineer.

DEATH

It was with deep regret that we learned of the death on the 13th September of **Chief Petty Officer P. J. McKenna, Technical Member,** of HMCS Shearwater. He had served on the Programmes Committee of the Halifax-Dartmouth Branch since its inception.

ADMISSIONS

At a meeting of the Admissions Committee, held on the 12th September, 1958, the following were admitted to the grades shown.

Member

J. G. Davidson (on transfer from Technical Member)

F/O B. B. Finn, RCAF, Engineer Officer, 5 Helicopter Operational Training Unit, RCAF Stn. Rockcliffe, Ont.: *64 Via Venus, RCAF Stn. Rockcliffe, Ottawa 2, Ont.*

W/C R. R. B. Hoodspith, RCAF, O.C. No. 1 Radar & Communications School, RCAF Stn. Clinton, Ont.

R. W. Peirce, Manager, Aeronautical Sales, Canadian Curtiss-Wright Ltd., 1980 Sherbrooke St. W., Montreal, P.Q.

W. Skelding, Personal Assistant to General Manager, Rolls-Royce of Canada Ltd., Box 1400, Stn. O, Montreal, P.Q.

T. E. Trempe, Section Head, Canadair Ltd., Montreal, P.Q.: *10574 Christoph Colomb, Montreal, P.Q.*

R. D. Williamson, Operations Assistant to Director of Telecommunications, Trans-Canada Air Lines, International Aviation Bldg., Montreal, P.Q.

Technical Member

F. B. Court, Design Draftsman, Lucas-Rotax Ltd., Scarborough, Ont.: *3882 Bathurst St., Apt. 1, Downsview, Ont.*

G. S. Critchley (on transfer from Junior Member)

W. Deacon (on transfer from Junior Member)

D. H. Goard, Principal, Vancouver Vocational Institute, 250 W. Pender, Vancouver 3, B.C.

F/O T. L. Jeary (on transfer from Student)

G. Mark (on transfer from Junior Member)

W. McDonald, Engine Tester, Bristol Aero Engines (Western) Ltd., Vancouver, B.C.: *449 Moncton St., Steveston, B.C.*

R. J. Simone, Junior Engineer, Canadian Pacific Air Lines (Repairs) Ltd., Calgary, Alta.: *3904 - 31st St. S.W., Calgary, Alta.*

Junior Member

L. Zelen, Draftsman, Canadian Pacific Air Lines (Repairs) Ltd., Calgary, Alta.: *4027 - 15th St. S.W., Calgary, Alta.*

Associate

A. A. Macintyre, Section Head, Aircraft Branch, Dept. of Defence Production, Room 309, 56 Lyon St., Ottawa, Ont.

J. B. Silvester, Production Officer, Dept. of Defence Production, Ottawa, Ont.: *1 Lesbury Ave., Brampton, Ont.*

L. J. Sinnott, Training Supervisor, Bristol Aircraft (Western) Ltd., Winnipeg, Man.: *1077 Dorchester Ave., Winnipeg 9, Man.*

J. D. Smith (on transfer from Junior Member)

SUSTAINING MEMBERS

NEWS

Computing Devices of Canada Ltd., in collaboration with Epsco Incorporated, has been charged with the design and construction of a multi-location weapons system range data processing system at Cold Lake RCAF Station, Grande Centre, Alta.

Some of the equipment is to be installed at Cold Lake, the rest at adjacent Primrose Lake. Test flight data is to be gathered at the Primrose Lake Primary Data Collection facility and relayed via a radio pulse code modulation link to the Data Processing installation at Cold Lake.

Information received at Primrose Lake will be in the form of frequency modulation and pulse duration modulation telemetered signals from the missile or aircraft under test. In addition to converting the primary data to PCM form for transmission to Cold Lake, the Primrose equipment will convert the information directly into analogue form for "quick look" real time evaluation. The analogue information will be tape recorded for stand-by and for future analysis.

Following conversion to PCM form at Primrose Lake, the telemetered data and the range timing signal will be transmitted up range to Cold Lake, where the information will be decommutated and recorded on magnetic tape in computer format. The Cold Lake facility will also contain a "quick look" recording system so that analogue information can be recovered with high accuracy for direct real time visual observation.

Besides the in-flight data to be processed at Cold Lake, a sub-system is to be provided to check out missile instrumentation prior to firing. The missile parameters in the form of PM or PDM signals are to be transmitted over a short distance, discriminated and recorded in real time analogue form available for pre-flight analysis, as well as incorporation into computer format.

Housed in 18 racks, the equipment includes two Epsco high speed reversible analogue-to-digital converters, ten of Epsco's Model FM-102 dual channel discriminators and a DR-704 digital computer format tape recording system.

Other equipment includes over 120 precision bandpass and lowpass filter units, several PDM-to-voltage converters, electronic multiplexers and a Time Code Translator Unit. Self-correction for errors in the analogue tape mechanisms is provided by Epsco velocity deviation detectors.

Bristol Aero Engines Ltd. has formed an Aviation Services Division. This newly formed Division is now functioning at Montreal Airport, Dorval, and is designed to perform aircraft ramp handling and maintenance services on behalf of scheduled and non-scheduled carriers.

De Havilland Aircraft of Canada Ltd. held the first public and press demonstration of the new DHC4 Caribou on the 17th September at the Downsview facility. A group of 1,000 visitors came from many parts of Canada and the U.S.A. – a substantial quota by air. Britain's new De Havilland Comet IV brought the Minister of National Defence, the Chiefs of Staff of the Navy, Army and Air Force, and other important Government officials from Ottawa to witness the demonstration. Many high ranking U.S. Army officers were among the interested spectators.

On the rain soaked grass strip the Caribou demonstrated its STOL ability by taking off, at practically full gross load, in a distance of 325 ft and landing on a wet field in less than 400 ft. A fast cruise fly-past demonstrated the aircraft's cruising speed of close to 190 mph. In the slow fly-past configuration, excellent control and handling qualities were demonstrated at speeds as low as 65 mph.

A static loading demonstration attracted a good deal of favourable comment. The Caribou's inwardly retracting rear loading door and adjustable ramp enable loads up to 1,000 cu ft capacity to be quickly transferred from transport vehicles to the aircraft's cabin. Two jeeps can be wheeled into the cabin under their own power, using a ramp which can be stored aboard the aircraft.

The original design concept of the Caribou was that of a "twin engine Otter". Design studies, however, revealed the case for the small twin was not very encouraging if substantial payloads were to be an important consideration. The final version has outgrown the original concept in size, but the primary design objectives have been achieved.

The Caribou is designed to operate from short unimproved fields under all-weather conditions. Its cabin will accommodate mixed loads of passengers and cargo. Maximum passenger capacity is 27 seats (military version seats 28 troops); 7,180 lb cargo can be carried, with fuel for 200 miles, including reserves. Ultimate range is 1,350 miles.

The angle of climb immediately after takeoff is better than 20° in a flat calm – a distinct advantage for clearing obstacles. Total distance from beginning of takeoff to clear a 50 ft obstacle is 800 ft with zero wind, or 460 ft with 20 mph headwind at full gross weight.

The undercarriage retraction is very rapid to enable the pilot to "clean up" the airplane quickly in case of engine failure.

An outstanding feature of the Caribou is its excellent controllability on one engine at very low speeds – almost down to stall. The large fin and rudder make this possible. Performance on one engine is very good. With two-speeds blower, the single engine service ceiling is nearly 15,000 ft – ample to continue flight to destination under full IFR conditions.

The landing approach, with full flap, is made at less than 70 mph. Touch down speed is less than 60 mph.

The airplane has been designed with both civil and military requirements equally in mind. As a civil utility transport, the Caribou will provide "air bus" service from short strips located close in to centres of population, heretofore accessible only to light airplanes. The military version is designed to provide close support in forward battle areas, carrying out aerial supply dropping, movement of men and supplies, and casualty evacuation.

BOOKS

Conference on Extremely High Temperatures. Edited by HEINZ FISCHER and LAWRENCE C. MANSUR. Sponsored by the Electronics Research Directorate, USAF, Cambridge Research Centre. John Wiley and Sons Inc., 1958. 258 pages. Illus. $9.75.

The above volume contains 22 papers (one of which is an abstract) which were presented at the first annual conference, at Boston, Mass., during 18 and 19 March, 1958. Since the various topics were mainly a report on work in progress on the production, analysis and application of ultra-high-temperature gases, the editors are to be commended for producing a competent record of the proceedings in such a short time. (There are occasional minor errors, for example, the interchange of the speed of sound with the speed of light, p 112.)

This book is of considerable interest to aeronautical engineers and scientists, despite the fact that it deals with such diverse and exotic topics as magnetogasdynamics, electric arcs, microwave thermometers for millions of degrees, plasma guns, shock waves with radiation effects, spectral-line broadening theory, production of magnetic fields in the megagauss range, and thermonuclear propulsion. This is part of the growing unity which has developed in the various branches of the physical sciences in the past few years. Probably no other branch of engineering has been affected to the same degree by this unity as the field of aeronautics. Aeronautical engineers are interested in temperatures in the range of thousands of degrees, associated with heat transfer effects at hypersonic speeds, up to temperatures in the millions of degrees, required for the producing of efficient thermonuclear astronautical propulsion units. The various papers will give them an insight into the problems and some of the recent advances that have been made towards their solution.

The 22 papers are broadly divided into 4 sections, as follows: (A) The Production of Extremely High Temperatures, (B) Methods of Temperature Measurement-Optical Radiation, (C) Plasma Analysis, and (D) Applications. Needless to say this is not a textbook. It will be most useful to those who already have some experience with the subject. Nevertheless, the papers are of varying complexity and scope and could also be beneficial to many seeking an acquaintance with the research and development in these new and interesting fields.

DR. I. I. GLASS

Aircraft and Missile Propulsion, Volume 1. By M. J. ZUCROW. John Wiley & Sons, Inc., New York, 1958. 538 pages. Illus. $11.50.

This is the first volume of a three volume work on aircraft and missile propulsion, the later volumes of which will deal with cycle analysis and performance characteristics of propulsion engines (Vol. 2) and propulsion engine components (Vol. 3). Considering the vast amount of literature already extant on this general subject, it is perhaps reasonable to wonder whether the addition of three more sizable volumes is really necessary. Judging from the present book, such doubts would appear to be unfounded. In the first place, it is possibly axiomatic that there can never be enough good books in a given field to preclude the publication of another. A good book may be defined as a book written for a significant purpose which is achieved. The purpose of the present book is to teach. It achieves this purpose admirably. Written primarily for students and for practising engineers who are not specialists in propulsion, the fundamental flow processes encountered in propulsion engines are treated in a remarkably lucid and consistent fashion.

Chapter headings include: (1) Review of Fundamental Principles, (2) General Characters of Propulsion Systems, (3) Thermodynamics of Compressible Fluid Flow, (4) Flow through Nozzles, (5) Flow through Diffusers–the whole developed in an orderly and logical progression, making for easy assimilation of the large amount of information made necessary by the rapid advances in propulsion units and the great extension of their operating environments occurring in the last few years. Indeed the major justification of the book probably lies in a treatment of fundamental principles, which takes cognizance of the fact that air breathing engines are now being called for to propel aircraft at Mach 3 and that current missiles possess hypersonic capabilities.

The text is liberally sprinkled with well-chosen worked examples, clear figures, complete tables and charts, useful bibliographies and, unfortunately, typographical errors. Due to the general clarity of the presentation, the latter are obvious and not likely to trouble anyone. It was particularly distressing, however, in a book dealing with the fundamental principles of propulsion, to notice an error in, of all places, the statement of Newton's First Law.

R. A. TYLER

Fundamentals of Hydro- and Aeromechanics. BY PRANDTL AND TIETJENS. McClelland & Stewart Ltd., Toronto, Ont., 1958. 270 pages. Illus. $2.05.

For the person whose prime interest lies in the field of present day aircraft without too much concern for Hypersonics, Part III of this edition "The Dynamics of Viscose Fluids" will be most interesting. For this person the chapter dealing with meteorology and airships will in all probability only be considered interesting background material.

In general this is the type of book that should be reviewed periodically, particularly by the graduates of 8 to 10 years ago. The development of basic concepts is excellent, the logical order and in some cases the different mathematical approaches tend to make the ideas easier to grasp.

A standard work of this kind would serve as an excellent jump-off for present day developments. As a matter of fact one feels that although the author is striving for the ideal situation, i.e. the complete marriage of the hydro-dynamic theory and the empirical hydraulic formula, it has not been accomplished primarily because the mathematical solutions were considered too cumbersome to be practical. If this text were rewritten with the concept that the readers had access to our present day computers it is quite possible that this union might have become a reality.

W. A. B. SAUNDERS

Interavia ABC, Directory of World Aviation, Sixth Edition. Interavia, Geneva 11, Switzerland: Interavia Canada, 25 Farmcote Rd., Don Mills, Ont. 1347 pages.

The 1958 edition of the Interavia ABC, Directory of World Aviation, is like its predecessors an imposing work, ingeniously indexed so that its great fund of information is fairly readily available. Inevitably it is last year's information and, for this reason, it is misleading and unreliable so far as its "who's who" elements are concerned.

However, its "who's who" elements are perhaps of little value to the technical man; for him there is some interest in a section, known for some obscure reason as the "Indicator", which by its own admission is "a five-language alphabetical glossary" of aeronautical terms. The five languages are English, French, German, Italian and Spanish. For the more common terms this vocabulary might be quite useful, if the English-

speaking reader is on his guard against the varieties within the English language itself, e.g. Accumulator/Battery. No doubt similar hazards are present in the other four languages and a note to explain whose usage of each language has been adopted would be helpful.

But the Indicator is a small portion of the whole and the remainder, in this reviewer's opinion, is too ambitious and lists too many details to be trustworthy in so fluid a medium as World Aviation.

H. C. LUTTMAN

History of German Guided Missiles Development. AGARDOGRAPH 20. Edited by T. BENECKE AND A. W. QUICK. E. Appelhans & Co., Brunswick, Germany, 1957. 420 pages. $7.50.

The Advisory Group for Aeronautical Research and Development of NATO organized a symposium, in April 1956, on the development of German guided missiles. The symposium was held in Munich, Germany, and many scientists and engineers who took an active part in missile development in Germany, before and during the last world war, gave summaries of their work.

The 26 papers are concerned with all phases of missile development, including aerodynamics, control, guidance and propulsion. The book is of great historical value and of technical interest in that it shows the complete development of the V-1 and V-2. Also a number of developments which did not come to completion are included. Very instructive are, for instance, the papers: The Aerodynamic Development of the V-2 by H. H. Kurzweg, and Development of the V-1 Pulse Jet by F. Gosslau, describing how the necessary data were obtained, starting from scratch.

In view of the price, few engineers will buy a personal copy. However, the book should find a useful place in the libraries of firms and institutions.

J. A. VAN DER BLIEK

The Metallurgy of Vanadium. BY W. ROSTOKER. John Wiley & Sons, Inc., New York, 1958. 185 pages. Illus. $8.50.

The appearance of Dr. Rostoker's book at this time is very fitting, since vanadium is becoming increasingly important as an alloying element for metals being used in high speed aircraft and missiles.

The principal role of vanadium today is as an alloy addition to titanium and to steel so as to develop high mechanical properties both at room and elevated temperatures. The comparatively new group of steels used for aircraft construction, which retain high strength in the vicinity of 1,000°F, and can be heat treated in heavy sections to develop an ultimate tensile of 300,000 psi or more, contain small quantities of vanadium.

In his book, Dr. Rostoker has done an excellent job of accumulating a great deal of information on such a comparatively new element. The information presented is based primarily on the results obtained from research programs sponsored by the Materials Laboratory of the Wright Air Development Center of the U.S.A.F. Much of the work on these programs was done by the author himself. Since a lot has yet to be learnt about vanadium, essentially in alloy form, the book should be considered really as a progress report.

The author presents in great detail such information as the extractive metallurgy of vanadium, a very comprehensive list of physical properties, alloy constitution diagrams, data on melting, casting, working, electro plating and methods of joining – just to mention a few of the items covered. A complete chapter is devoted to the metallography of vanadium and its alloys.

However, to this reviewer's mind, the most significant chapter deals with vanadium as an alloy addition, since this is where its present and immediate future importance lies. Dr. Rostoker explains rather comprehensively, for example, the mechanism by which vanadium imparts such excellent properties to steel.

In summary, "The Metallurgy of Vanadium" should be in the reference library of every aircraft and missile metallurgist since it is considered that vanadium will become increasingly important in these industries.

It might be interesting to Journal readers to know that Dr. Rostoker received his Bachelor's and Master's degrees in Applied Science at the University of Toronto. He is considered to be, by the metallurgical profession at least, an authority in several phases of this field, particularly in that of titanium. At the time of writing of his book, he was Assistant Manager of the Metals Research Department of the Armour Research Foundation in Chicago.

J. J. WALLER

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Position Required

Box 105 **Executive:** Qualified and experienced Engineer seeks position of Assistant to President or General Manager with the possibility of promotion to executive rank. Age 41 years, present salary approximately $15,000 per annum.

Positions Vacant

Design Engineer: Current experience in mechanical or structural design, with some knowledge of electrical installations; good draftsman, familiar with office procedures; Member grade preferred. Personnel Manager, Spartan Air Services Ltd., 74 Sparks St., Ottawa 4, Ont.

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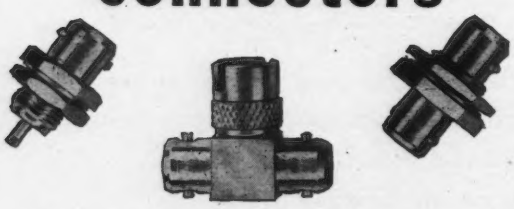

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SPECIALIST SECTIONS

MEMBERSHIP REQUIREMENTS

At the present time there are three Specialist Sections of the Canadian Aeronautical Institute. To be a member of a Section, it is necessary firstly to be a member of the Institute and secondly to possess certain qualifications peculiar to the Section concerned. These identifying qualifications are set out in the following extracts from Section Regulations.

TEST PILOTS SECTION

All members of the Institute who are or have been engaged as pilots in experimental, development, production or maintenance flight testing shall be eligible for membership of this Section.

PROPULSION SECTION

All members of the Institute who are or have been engaged in technical work on propulsion systems shall be eligible for membership of the Section.

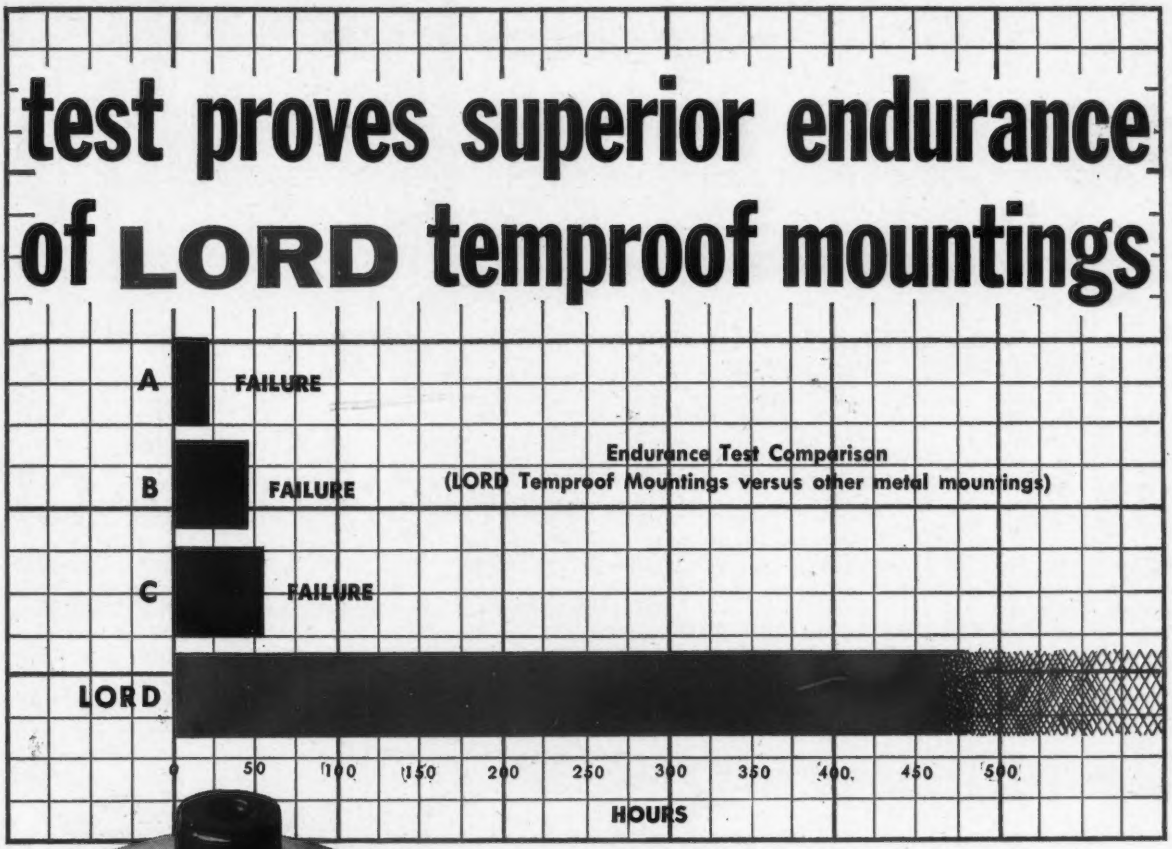
ASTRONAUTICS SECTION

All members of the Institute who are or have been engaged in technical work related to guided flight or space vehicles or who possess technical knowledge of the science and engineering of astronautics shall be eligible for membership of the Section.

Any member of the Institute wishing to be admitted to a Section should apply on a special form which can be obtained from Branch Secretaries or from C.A.I. Headquarters.

Membership of a Section does not entail the payment of any entrance fee or annual dues additional to those normally payable for membership of the Institute.

test proves superior endurance of LORD temproof mountings



LORD TEMPROOF MOUNTING

PURPOSE: To compare the endurance of several commercial vibration isolators used in the aircraft and missile electronics field. Test was conducted by an independent laboratory.

TEST CONDITIONS: Three competitive models, in sets of four mountings each, were placed under loads of 16 pounds and vibrated simultaneously at frequencies from 5 cps to 44 cps at a double amplitude of .060".

RESULTS: At the conclusion of the test only the LORD Temproof Mountings had functioned 425 hours and were still in service—with no significant change in vibration characteristics. Mounting "A" failed in less than 20 hours . . . mountings "B" and "C" failed in less than 60 hours.

CONCLUSION: "The LORD Temproof Mounting is more durable than the other vibration isolators tested."

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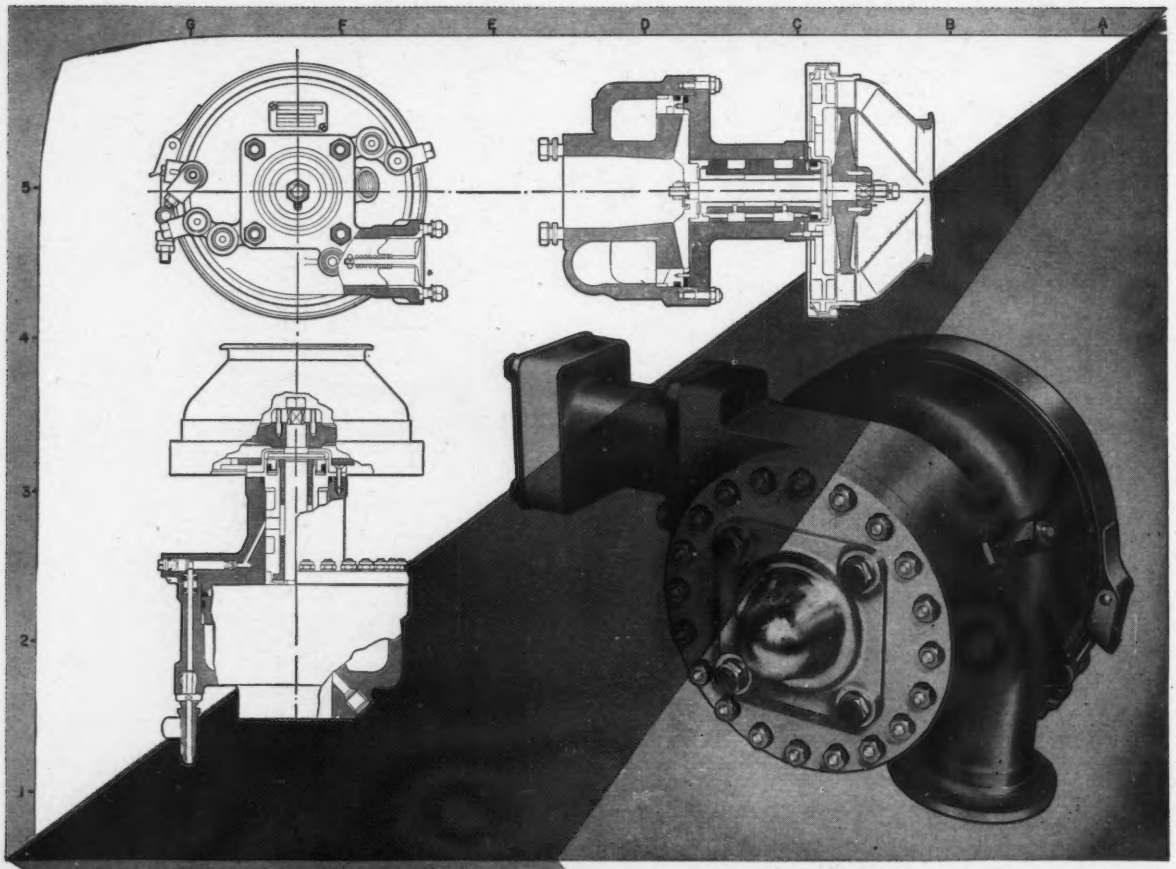

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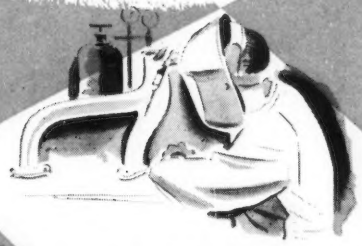

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